# Stress-Strain Response of BCSA Cement Concrete

## Research on BCSA cement is expected to help codify its use as an alternative cement

*by Victoria K. Sicaras, on behalf of the ACI Foundation*

As the global construction industry intensifies focus on sustainable infrastructure and rapid construction, structural engineers are turning to alternative cements for their environmental characteristics and specialty properties. While alternative cement concretes are allowed in design under ACI 318-19(22), "Building Code Requirements for Structural Concrete and Commentary," they must first be proven to conform to the existing design parameters used to estimate performance. Yet often, there is not enough data available to prove the materials meet the parameters of ACI 318-19(22)—or whether those parameters, developed for portland cement concrete, are applicable for alternative cements.

This has posed a problem for specifying materials such as belite calcium sulfoaluminate (BCSA) cement—a promising alternative hydraulic cement for structural repairs and new precast concrete construction. Known for its high-early-strength and fast-setting properties, BCSA cement exhibits high sulfate resistance, adequate durability, and a lower carbon footprint when compared with portland cement. However, there has been limited research to characterize the performance of concrete made with this specific type of cement in ultimate strength design.

"I've been doing research with rapid-setting BCSA cement concrete for about 8 years now," said Cameron Murray, Associate Professor at the University of Arkansas, Department of Civil Engineering, and a member of ACI Committee 242, Alternative Cements. "This cement has been around since at least the 1980s and has great potential for rapid construction and structural repairs, but there previously wasn't a lot of published work on its structural performance. Precise structural properties were never measured."

Murray's latest research is helping to clear that hurdle. In 2023, his team at the University of Arkansas, Fayetteville, AR, USA, completed "Stress-Strain Analysis of BCSA Cement for Structural Applications," a 2-year research project funded by

### Project Details

**Name:** Stress-Strain Analysis of Belite Calcium Sulfoaluminate Cement for Structural Applications

**Principal Investigator:** Cameron Murray, Associate Professor, University of Arkansas, Department of Civil Engineering

**Graduate Research Assistants:** Gabriel Johnson (Graduate Student) and Elizabeth Poblete (PhD Student)

**ACI Technical Committee endorsement:** 242, Alternative Cements

**Funder:** ACI Foundation

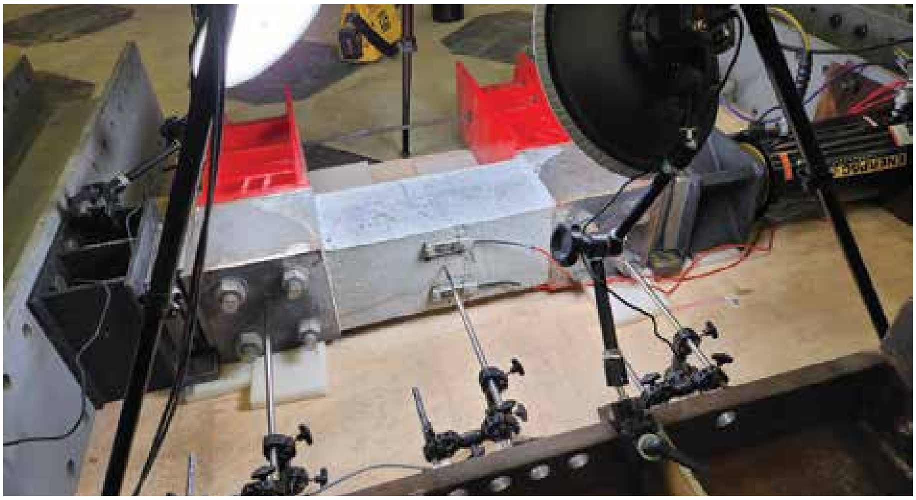
**Industry Partner:** CTS Cement Manufacturing Corp.

**Advisory Panel:** Eric Bescher, Lisa Burris, Mary Christiansen, Chris Ramseyer, Robert Thomas, and Ken Vallens

**About the Research:** The project compares the stress-strain relationship of BCSA cement concrete in both uniaxial compression and flexural compression loading to that of portland cement concrete. It also provides guidance on the applicability of current ACI Code values for the design of BCSA cement concrete flexural members. The project had three objectives:

1. Develop an appropriate value of ultimate compression strain for BCSA cement concrete.
2. Investigate the stress distribution in BCSA concrete at the nominal moment capacity.
3. Measure axial compressive stress-strain response for BCSA concrete at different ages.

Research results indicate that BCSA cement concrete behaves similarly to portland cement concrete in compression and has similar modulus of elasticity (MOE) and compression strain characteristics. In combination with past work published in ACI journals, the researchers concluded that flexural design with BCSA cement concrete can be carried out in the same way as for portland cement.



**Test setup used to perform the flexural compression testing for the stress-strain analysis of BCSA cement specimens. The specimens were tested horizontally; all the gray steel pieces were attached to the strong floor to provide a reaction to the applied loads. For scale, the spacing of the octagonal steel plates in the floor is 4 ft (1.2 m)**

the ACI Foundation. The project's primary purpose was to measure ultimate strain and stress behavior and perform controlled experiments to verify that ACI 318-19(22)'s flexural capacity procedures can work for concrete made with BCSA cement. The results indicate that BCSA cement concrete behaves similarly to portland cement concrete in compression and has similar modulus of elasticity (MOE) and compression strain characteristics.

"We found that the stress block parameters and flexural design assumptions in the ACI Code can be applied to BCSA conservatively. In combination with past work published in ACI journals, we've concluded that flexural design with BCSA cement concrete can be carried out the same way as for portland cement," Murray said.

The project's final report can be found at **www.acifoundation.org/Portals/12/xBlog/uploads/2023/10/26/0045FinalReport.pdf**. The technical knowledge gained will be used to inform an upcoming report by ACI Committees 318 and 242 on BCSA cements, as well as updates for two technical committee reports: ITG-10.1R, "Report on Alternative Cements," and ITG-10R, "Practitioner's Guide for Alternative Cements." In addition, the information could be used to help codify the use of BCSA cement in structural applications.

ACI Foundation Executive Director Ann Masek said the Foundation was pleased to support Murray's work and help advance the concrete industry's knowledge on BCSA cement.

"A structural designer needs to be confident that the behavior of the material used can be predicted accurately by design codes," Masek said. "The results from this project will help promote that confidence in BCSA cement and also present new information that can be used to design structures with the cement more efficiently."

In addition, Masek continued, the work can serve as an example for future projects investigating flexural performance of other alternative cements.

## Building on Previous Research

"One important consideration in terms of structural performance of concrete is the flexural stress-strain response. This is a fundamental part of how we do strength design of flexural members in the ACI Code," Murray said.

Having ultimate compression stress and strain data is necessary to ensure safe and proper designs. For example, an increased compression strain value has many design implications for beams, columns, and slabs. More steel can safely be used in a section, or shallower sections can be used if the compression strain is increased.

Murray had previously tested and compared reinforced concrete beams cast with BCSA cement against portland cement concrete beams to determine the applicability of ACI 318-19(22) flexural strength provisions. The beams performed similarly, with one major exception: The ductility of BCSA beams was higher, even at lower compressive strengths.

"This initial research suggested that the ultimate compression strain of BCSA concrete is different than portland cement, and the traditionally assumed value (0.003) for normal-strength concrete should be revised for BCSA," Murray said. "We needed to explore it further."

The next step was to investigate the ultimate compression strain capacity of BCSA cement concrete and determine a reasonable value for its use in structural design. To gain funding for this endeavor, Murray submitted a project proposal to the ACI Foundation's Concrete Research Council (CRC).

The CRC's request for proposal (RFP) program awarded funding to several concrete research projects each year. This project was awarded based on relevancy and potential impact of the research, overall proposal quality, researcher capability, supplemental support for the project (for example, collaboration with other funders and organizations), and ACI technical committee engagement. Murray's BCSA stress-strain analysis proposal was endorsed by ACI Committee 242 and supported by CTS Cement Manufacturing Corp.

The project was awarded funding in 2021. As principal investigator, Murray led a research team that included Graduate Student Gabriel Johnson and PhD Student Elizabeth Poblete. Tests were conducted at the University of Arkansas's Grady E. Harvell Civil Engineering Research and Education Center.

## Stress-Strain Analysis Experiments

To measure the ultimate stress and strain behavior of BCSA cement, the researchers uniaxially tested a total of 64 concrete cylinders at various water-cement ratios (*w*/*c*) and ages. They also measured strains to determine MOE. Of the 64 cylinders, six were control cylinders of portland cement concrete and 58 were BCSA cement concrete specimens. From these tests, uniaxial stress-strain relationships were developed, and MOE and maximum strain values occurring at maximum stress were compared with historical data.

To evaluate compression zone properties of BCSA cement concrete for reinforced concrete design, the team fabricated 14 unreinforced flexural compression specimens at various *w*/*c* and tested them in combined axial compression and bending at different ages. Variables in this study included *w*/*c*, age at testing, and compressive strength. Again, the results were compared against historical results and design code estimates.

"A major challenge was developing the testing methodology," Murray said. "We had to build special rollers for each end of the samples and construct a rigid testing frame on the strong floor at the structural engineering laboratory. This frame had to resist loads at failure approaching 300,000 lb [1334 kN]."

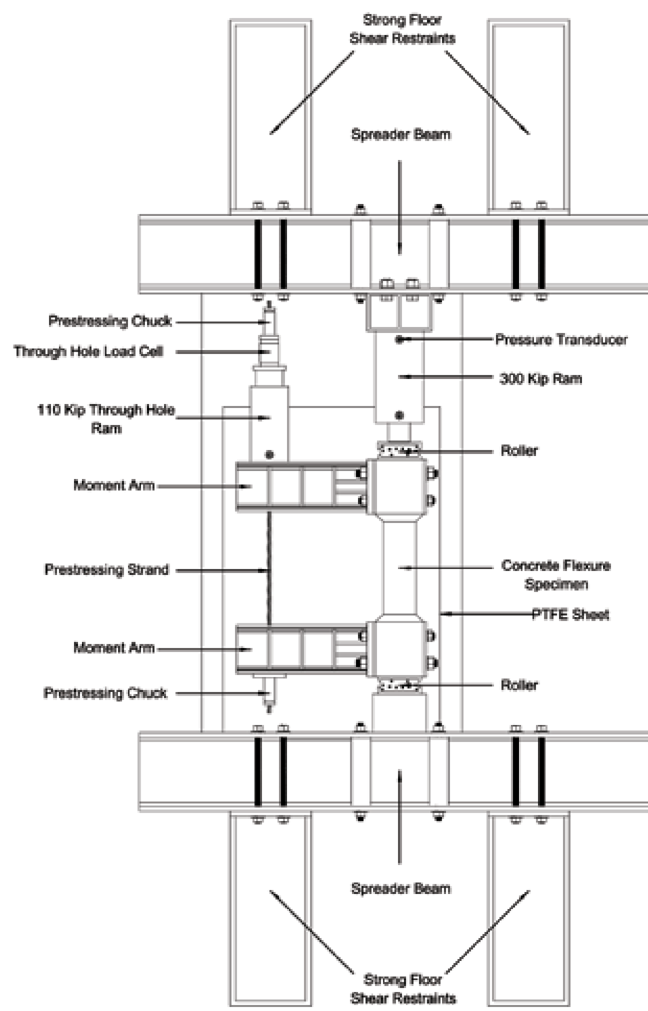
The team spent months refining the test setup, developing formwork and connections for the samples, and testing preliminary samples to perfect their measurement techniques. They used digital image correlation (DIC) to measure strains on the samples, which Murray said was their first experience applying DIC in their research.

"Another challenge was actually performing the tests," Murray added. "Our samples often failed at loads exceeding 290,000 lb [1290 kN] of total force. Because these were flexural compression tests on unreinforced concrete, the samples would fail with little warning and in an explosive manner. Those were some tense days at the lab!"

Results from the uniaxial compression cylinder tests indicate that BCSA cement concrete behaves similarly to portland cement concrete in compression and has similar MOE and compression strain characteristics. Results from the flexural compression specimens suggest that concrete design code equations for estimating design parameters for flexural members are adequate or conservative for BCSA cement concrete flexural members with compressive strengths between 7800 and 12,400 psi (54 and 86 MPa).

"This study and other work done in my lab have shown

**Students Gabe Johnson and Elizabeth (Bette) Poblete ran most of the tests that went into the report and assisted with the article. Pictured in front is Poblete calibrating the digital image correlation system**




**A plan view of flexural test setup**

that in spite of having major chemistry differences to portland cement, BCSA cement performs surprisingly similar to portland cement in structural concrete," Murray said.

## Critical Support from Industry and the ACI Foundation

Due to his past work, Murray had developed a relationship with CTS Cement, a California, USA-based cement company that makes BCSA cement. The company provided technical and in-kind support for the stress-strain analysis project.

"CTS has a long history of supporting research dating back to its founder, the late Ed Rice," Murray said. "A structural engineer and ACI Fellow, he believed strongly in the application of these cements to structural concrete, so I think it is fitting that CTS helped support this project."

Murray also is thankful to have gained the ACI Foundation as a key funder. The Foundation's mission is to make strategic investments in ideas, research, and people to create the future of the concrete industry.

"I have been involved with ACI for more than 10 years now, dating back to my time as a student. It is professionally very rewarding for me to work directly with ACI through the Foundation on this research," he said.

A former ACI Foundation fellowship recipient, Murray encourages his students to apply for ACI Foundation scholarships as well as attend ACI Concrete Conventions and become involved with professional committees. Of the two research students working on the stress-strain analysis project, Gabriel (Gabe) Johnson was awarded a 2022-2023 ACI Foundation Scholarship (refer to the sidebar). Johnson—now a PhD Student—performed all the sample preparation, testing, and analysis. He co-wrote the final report and resulting article.

"This was a challenging project, and Gabe has done a fantastic job seeing it to the end," Murray said. "He presented

### Gabriel Johnson, University of Arkansas
### 2022-23 ACI Foundation Scholarship recipient

Johnson

A critical component of the ACI Foundation's mission is to invest in the future of the concrete industry by awarding scholarships and fellowships to eligible students whose studies are related to concrete.

"It's especially rewarding to see scholarship recipients like Gabriel Johnson involved in current research impacting the industry," said Ann Masek, Executive Director of the ACI Foundation. A 2022-2023 recipient, Johnson applied for the ACI Foundation Scholarship while working as a Graduate Research Assistant on the Stress-Strain Analysis of BCSA Cement for Structural Applications project.

"Every so often we get to see instances where our different initiatives dovetail, with the students we support contributing in significant ways to the projects we fund," Masek said.

After he received his BS in civil engineering from LeTourneau University, Longview, TX, USA, Johnson was accepted into the master's degree program at the University of Arkansas College of Engineering. He arrived at the campus in 2021 with a deep concern about carbon dioxide output and resource use in construction. This has translated to a passion to reduce carbon emissions with alternative cements such as BCSA cement.

"Gabe helped us set up our new structural engineering laboratory and has since been an integral part of my research group," said Associate Professor Cameron Murray, Principal Investigator of the BCSA cement stress-strain analysis project. As Johnson's advisor, Murray suggested he apply for the ACI Foundation scholarship opportunity.

"Dr. Murray encouraged me to apply due to the nature of our research," Johnson said. "Alternative cement materials and reduction of greenhouse gas emissions during cement production is always of interest to the industry, and we were encouraged that the Foundation was available to help us."

ACI Foundation staff members Chandice Moore and Tricia Ladely provided assistance during the application and acceptance process, which Johnson said was of great help to him.

The scholarship covered the cost of Johnson's graduate school classes and fees, which allowed him to focus his time and efforts on classwork and lab work without the need for supplemental income. Through the BCSA research project, he was able to attend the ACI Concrete Convention in New Orleans, LA, USA, to present project results, as well as provide updates to ACI Committee 242 at ACI Conventions in Orlando, FL, USA; Dallas, TX; San Francisco, CA, USA; and Boston, MA, USA. Attending these conventions allowed the graduate student to expand his professional working relationships and receive valuable input from the BCSA advisory panel.

"I felt extremely honored to receive the ACI Foundation Scholarship," Johnson added; he is now a doctoral student at the university. "The award allowed me to continue researching the structural properties of alternative cement concrete."

Johnson hopes to remain in research to help develop methods and materials that cut carbon dioxide output in cement production. He is also interested in developing strategies to cut carbon, costs, and resource use in concrete infrastructure rehabilitation and repair projects.

our work at ACI Conventions and represented the project and our university well."

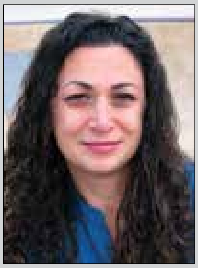
## Next Steps

The stress-strain analysis study helped add to a growing body of work demonstrating that BCSA cement is a viable alternative cement to build concrete structures. In applications where speed is of the essence, such as for precast or prestressed concrete and accelerated construction or repair, Murray said the cement is "ready for game time."

There is already documented information about controlling the setting time of concrete made with BCSA cement, as well as proportioning mixtures, properties and advantages, and performance. In Murray's lab alone, researchers have studied its shear strength, flexural strength, MOE, tensile strength, and now stress-strain response. However, there are still open research questions to answer, mostly about durability. Murray's graduate students are currently studying the cement's use in extreme temperatures and testing how curing time and cover depth can affect corrosion resistance.

Murray would like to see more studies on BCSA cement in real-world applications. "The biggest things I would like to see are some full-scale demonstrations and trials," he explained. "This is just my opinion, but a lot of what we know about portland cement came about by applying it to real-world applications over the past two centuries and seeing how it did. I think we need to take some measured risks with alternative cements so we can learn more. If anyone wants to try to build a structure with this cement, I want to help."

To help further similar research projects, the ACI Foundation continues to fund the people, research, and innovations that provide needed solutions. Organizations can aid the Foundation's efforts and support concrete-related research and technology advancements by contributing their expertise, experience, and donations. For more information, visit **www.acifoundation.org/giving**.



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