

The American Ceramic Society

2025 Cements Division

15th Advances in Cement-based Materials

Book of Abstracts

June 11-13, 2025

Boulder, CO

Keynote Speaker – Dr. Lori Tunstall

Wednesday, June 11, 2025, 9:15 – 10:00am

Toward Carbon-Negative Concrete: Bridging Scientific Innovation, Field Deployment, and Entrepreneurial Thinking

Concrete's ubiquity makes it a critical focal point for global decarbonization—and a compelling testbed for translating academic research into climate impact. This keynote will explore the potential of engineered biochar as a multifunctional, carbon-negative additive for cement-based materials, highlighting results from ongoing laboratory investigations, field trials, and standards development through ASTM. In parallel, I will reflect on how adopting tools from the entrepreneurial ecosystem — such as customer discovery, minimum viable product (MVP) frameworks, and rapid iteration—can complement traditional research approaches. These methods offer a structure for engaging stakeholders early, testing assumptions in real-world contexts, and aligning scientific inquiry with deployment pathways. By integrating entrepreneurial thinking into academic research, we can expand the role of materials scientists as climate innovators—and better position emerging technologies like biochar to meet the urgency and scale of global infrastructure challenges.

Keynote Speaker – Dr. Jesse Benck

Thursday, June 12, 2025, 9:00 – 9:45am

Sublime Systems: Electrochemical Production of Next-Generation, Clean Cement

Sublime Systems has developed a new, more energy efficient, cleaner way to make cement. Our ambient temperature electrochemical process is powered by decarbonized electricity and produces low-carbon cement plus critical minerals as co-products. Sublime Cement® can be made from a wide range of non-carbonate feedstocks including abundant natural rocks and minerals or industrial waste materials. As a result, Sublime Cement™ avoids NO_x, SO_x, particulate, and greenhouse gas emissions arising from both the feedstock decomposition and heating in conventional portland cement manufacturing, while offering an ASTM C1157-compliant cement that can be used to produce concrete with the same ultimate strength and equal or better durability compared to portland cement concrete. Sublime Cement® has achieved remarkable decarbonization and has a technical path to greater than 90% decarbonization by 2030. Sublime is currently operating a pilot plant with a 100 metric ton annual capacity and plans to construct its first commercial-scale plant capable of producing greater than 22,000 tons per year of cement by 2027. In this presentation, we will provide an overview of our technology, test methodologies and results to date, and our path to scale our breakthrough technology and decarbonize cement manufacturing.

Della Roy Lecture – Dr. Kimberly Kurtis

Wednesday, June 11, 2025, 4:00 – 5:00pm

Greening Our Gray World: Sustaining Innovation and Translating Discovery in Cement and Concrete Science

The necessity and ubiquity of concrete infrastructure demand continued innovation to meet global societal needs—equitably, sustainably, and economically—while enabling more resilient and lower-carbon development. Yet shifting global and national priorities now pose risks to the momentum of scientific and technological progress in these fields. In this lecture, I will explore how advances in cementitious materials contribute not only to technical achievement but also to broader societal goals. I will highlight three areas where sustained innovation is essential—and where my own work has focused: advancing the fundamental characterization of cement-based materials, improving performance and durability to extend service life, and harnessing data analytics to accelerate design and specification. Sustaining progress requires not only research excellence, but also strong public engagement and industry collaboration to ensure that discovery translates into meaningful, sustainable impact.

A: Rheology and Additive Manufacturing

Wednesday, June 11, 2025, 10:15am - 12:15pm

10:15am - Abstract #3397

Effects of shear on rheological property development of alkali-activated binders (AAB's) studied via a model metakaolin geopolymer and aluminosilicate gel

Thaddeus M Egnaczyk and Norman J. Wagner, University of Delaware, Newark, DE

Abstract Text:

Successful design of cementitious materials for emerging applications like additive manufacturing requires control of rheology throughout the material's processing lifetime. During processing, a material may experience a wide range of shear histories depending on the type of mixing, pumping, or extrusion operations required. The reacting nature of cementitious materials imposes additional kinetic constraints, defined in part by the initial formulation and processing history. Alkali-activated binders (AABs), including geopolymers, are studied for their low carbon footprint and use of naturally occurring aluminosilicate materials or industrial aluminosilicates like fly ash and slag. However, valuable formulation guidance for successful AAB processing is achieved by studying model materials. Metakaolin based geopolymers are often studied due to their purity and high aluminosilicate content. Furthermore, aluminosilicate gels can be synthesized without the dissolution of an aluminosilicate source to isolate the crosslinking polycondensation reaction.

The goal of this work is to understand the effects of applied shear on both the rheological property development and final material properties of (1) a model metakaolin geopolymer and (2) a model aluminosilicate gel. A complete characterization of rheological property evolution for both the geopolymer and gel is captured via small-amplitude oscillatory shear (SAOS) using a novel application of optimally-windowed chirp rheology and steady-shear rheology. The geopolymer and gel are subjected to mechanistically designed shear protocols, varying the magnitude and duration of shear to mimic industrially relevant processing steps. The duration of applied shear relative to the rheological gel point of the material determines the rate of increase in the elastic modulus and network structure of the reacting binder. The seven-day compressive strength of geopolymers subjected to varying shear protocols is also measured. A mechanistic understanding of how processing parameters impact the rheological properties of geopolymer binders facilitates the design of optimized processing routines for emerging applications like additive manufacturing.

10:30am - Abstract #3452

Sensor network and post-manufacturing inspection: The strategy to guarantee quality of 3D printed concrete structures

Stefan Zimmermann, Danielle Griego, Matineh Mahmoudi and Robert J. Flatt, ETH Zurich, Zurich, Switzerland

Abstract Text:

Current 3DCP systems mainly rely on human experts performing adaptations depending on the state of the print material. The fate of a print relies on subjective experience rather than complete objective control over the print, which represents a challenge for industry to achieve their usual standards, hindering adoption of 3DCP.

To tackle these shortcomings, we have developed two major adaptations in the construction workflow of 3DCP: 1) sensor networks capable of monitoring the printed filament and 2) a quality control method of printed structures in the form of a post-manufacturing inspection from sensor data.

Detailed monitoring of 3DCP with a sensor network would contribute to multiple goals. First, it would help to understand the current conditions of a print, enabling more reliable, data-based adaptations to counter problems. Second, sensors would help document the final properties of a print. Synthesizing data into a digital twin model of a printed structure would allow safeguarding it for later analysis. Lastly, a sensor

setup would help with complete automation of the printing procedure without human intervention. This would further strengthen 3DCP's claim to solve the problem of labour shortage. In addition, we implement a post-manufacturing inspection using augmented reality headsets and data from the previously synthesized digital twin. In an inspector's field of view, a digital twin is overlaid onto a printed structure enabling easy access to manufacturing data. Overall, this inspection method would guarantee a certain quality standard for every printed structure and could contribute to the acceptance by industry.

To summarize, we believe that to overcome the worries of industry regarding 3DCP, a better sensor monitoring during the print and the establishment of a quality control after the print are necessary. We demonstrate approaches and ways to implement them in the hope to foster the trust necessary for industry to adopt 3DCP.

10:45am - Abstract #3544

Rheological characterization of 3D-printable ultra-high-performance concrete

Ayesha Ahmed, Raul E Marrero, Elmer Miguel Irizarry, Shady Gomaa, and Gianluca Cusatis, Northwestern University, Evanston, IL

Abstract Text:

The integration of additive manufacturing with ultra-high-performance concrete (UHPC) opens new opportunities for optimizing structural design by leveraging its exceptional strength and durability. This study presents an experimental framework for evaluating the rheological behavior of a nanomodified 3D-printable UHPC, serving as the basis for developing a thixotropy model tailored to concrete 3D printing. Rotational rheometry protocols were established to capture critical phenomena, including flocculation, deflocculation, reflocculation, and structural build-up, ensuring a comprehensive assessment of thixotropic behavior. Flow curve tests were performed at varying resting times to cover the range of shear rates encountered during printing. Additionally, to replicate the mechanical load from subsequent layers, a small constant shear rate was applied to samples with and without prior shearing, incorporating different resting times, enabling direct comparison of their rheological responses. Open time was assessed through flow curve measurements conducted at hourly intervals for up to ten hours. The findings demonstrated that shear history and resting time significantly influenced shear stress, emphasizing the importance of flocculation and deflocculation in rheological evolution. Furthermore, open time testing indicated that the material maintained consistent rheological behavior for up to ten hours after mixing when periodically sheared, representing the longest open time reported in the literature. Lastly, a thixotropy model was formulated based on these experimental insights, which showed good agreement with the data and was implemented in a Smoothed Particle Hydrodynamics (SPH) framework to simulate the rheological tests. These findings lay the groundwork for future CFD simulations of complex non-Newtonian fluids like UHPC.

11:00am - Abstract #3578

Multiscale investigation of 3D-printed earthen materials & structures

Samuel J. Armistead, Rebecca A. Mikofsky, and Wil V. Srubar III, University of Colorado Boulder, Boulder, CO, and Yierfan Maierdan, Olga B. Carcassi, Shiho Kawashima, and Lola Ben-Alon, Columbia University, New York City, NY

Abstract Text:

Nature provides a powerful blueprint for fabricating high-performance 3D-printed earthen materials and structures. Here, we introduce a multiscale, biomimetic approach that optimizes the physicochemical interactions between biopolymers and earthen minerals at the microscale and systematically scales preferred interactions across spatial dimensions, enabling the design and fabrication of macroscale, high-performance, 3D-printed earthen structures. We show that this multiscale approach converges on a

universally applicable alginate-based biopolymer stabilizer, with which we can achieve a 33% increase printing speed and a 10 degrees increase in structural stability which, in turn, can increase construction strength, speed, durability and the ability to print large-scale geometries which were previous considered unachievable. This multiscale biomimetic approach can be applied to elucidate microstructural design strategies for improving other material properties and performance characteristics, paving the way for high performance, sustainable construction in the 21st century.

11:15am - Abstract #3590

Concrete rheometry: Mission impossible?

Dimtri Feys, Missouri University of Science and Technology, Rolla, MO, and Shravan Muthukrishnan, Roman Rezaev, Daniil Mikhalev and Viktor Mechtcherine, Technische Universität Dresden, Dresden, Germany

Abstract Text:

Concrete rheometry has been of interest to the community since the early 1970s. Concerns with flow localization and shear-induced particle migration led to the development of complex rheometer geometries. With the introduction of polycarboxylate high-range water-reducing agents and self-consolidating concrete in the late 1990s, concrete rheometer design went back to “basics” with geometries resembling simple concentric cylinders or parallel plate systems. Since then, these devices are frequently used to characterize the rheological properties of conventional concrete too. However, are these geometries really adequate for that?

An inter-laboratory rheometer assessment campaign was conducted at TU Dresden (Germany) in November of 2023, evaluating the capacity and limitations of 10 different devices. Over 50 concrete rheological measurements were executed simultaneously on concrete mixtures with varying yield stress and plastic viscosity values. The major evaluation criterion was the likelihood of concrete flow which can be considered as that of a homogenous material. Analysis of the results has revealed that this likelihood decreases with decreasing ratio of H/G , with H the slope and G the intercept of the torque-velocity relationship. Smaller inner radii of the shearing unit also lower the chance that concrete flow during measurements can be assumed as homogeneous. However, measuring the rheological behavior of concrete remains crucial in mastering various challenges of the concrete industry and enabling its advancements. Therefore, the authors propose a series of alternative strategies to enable adequate characterization of fresh concrete.

11:30pm - Abstract #3640

Unraveling flow loss in superplasticized limestone calcined clay cement

Franco Zunino, University of California, Berkeley, Berkeley, CA

Abstract Text:

This study explores the causes of fluidity loss in superplasticized limestone calcined clay cement (LC3), which serves as a sustainable alternative to ordinary Portland cement (OPC). Despite its environmental advantages, LC3 faces challenges in maintaining workability when superplasticizers are used. This paper delves into the underlying mechanisms of these issues. The research focuses on the role of initial chemical reactions that increase surface area and how this affects the performance of polycarboxylate ether superplasticizers (PCE) in LC3. Experimental findings show that while PCEs initially disperse cement particles, the fluidity of the mix decreases quickly due to the ongoing generation of new surfaces, which eventually surpasses the adsorption capacity of PCEs. The study also investigates the possibility of PCE side chains intercalating into calcined clays and finds that even in the case of montmorillonite clays,

this intercalation does not significantly contribute to slump loss when the clays are calcined. The results suggest that to improve flow retention in superplasticized LC3 systems, alternative strategies may be needed, such as slowing the initial reactivity of the calcined clays. One potential approach is combining PCEs with other additives, like diphosphonates, to mitigate the loss of fluidity over time. These findings point to a need for optimizing the interaction between the superplasticizer and calcined clays to improve the long-term workability of LC3-based concrete.

B: Durability and Service Life Modeling

Wednesday, June 11, 2025, 10:15am - 12:15pm

10:15am - Abstract #3404

Sustainable bio-inspired self-healing concrete in mitigating chloride attack

Pardis Pourhaji and Nima Rahbar, Worcester Polytechnic Institute, Worcester, MA

Abstract Text:

Cement production is a major contributor to global carbon emissions, responsible for approximately 8% of emissions and 3% of energy demand. Resistance of concrete to chloride penetration is a critical factor in determining the durability of reinforced concrete structures. Recently, self-healing concrete has emerged as a promising solution to enhance this resistance. This study explores the use of carbonic anhydrase (CA), a biological enzyme, as a self-healing agent to mitigate chloride penetration in concrete. Concrete disk specimens were prepared with and without CA at two different dosages and cured. Chloride penetration depths and migration coefficients were assessed for uncracked specimens. Additionally, a lower dosage of CA was used to prepare cracked and healed specimens, with chloride content quantified to predict service life at 28 days. Results demonstrated that the incorporation of CA significantly improved the chloride resistance of uncracked concrete, with a reduction in chloride penetration by up to 46% compared to control specimens. While cracking increased chloride penetration, healing the cracks restored the chloride penetration depth to levels comparable to uncracked concrete. This study shows that CA enzyme not only extends the service life of uncracked concrete but also recovers the durability of cracked concrete after healing. The use of CA as a self-healing agent holds promising potential for improving infrastructure sustainability and reducing CO₂ emissions associated with cement production, offering a significant step toward more environmentally responsible construction materials.

10:30am - Abstract #3443

Biomining-induced degradation of portland cement paste

Caitlin J. Adams, Cansu Acarturk and Wil V. Sruar III, University of Colorado Boulder, Boulder, CO

Abstract Text:

Microbially induced calcium carbonate precipitation (MICP) “self-healing” has the potential to increase the durability and service life of concrete infrastructure by leveraging the efficiency of enzymatic pathways to mitigate performance losses due to crack formation. In the most used form of MICP, ureolytic microorganisms are provided a treatment media consisting of urea and often a calcium salt. However, the effects of these enzymatically driven processes are understudied beyond the qualification and quantification of biomining. This study investigated the effects of treatment media concentration on both MICP yield and portland cement (OPC) paste properties after MICP exposure. To explore potential effects, treatments were performed on both OPC paste cubes immersed in treatment media (*in-situ*) and treatment medias without cement (*ex-situ*). Three categories of treatment were investigated using commonly employed MICP reagents: (1) biotic media, containing *S. pasteurii*, calcium acetate, urea, and yeast extract; (2) abiotic media, containing calcium acetate, urea, and yeast extract; and (3) chemical media, containing acetate salts and ammonium salts, representing ionic side products of the urea hydrolysis reaction in MICP. All specimens were treated three times per week until testing at 7 and 28 days with limewater as a reference treatment. At each testing day, the *in-situ* OPC paste cubes, their supernatant, and the *ex-situ* solutions and any precipitates were characterized through a combination of pH, urea concentration, compressive strength testing, thermogravimetric analysis, and x-ray diffraction.

Results showed reductions in strength and portlandite content of cement paste exposed to MICP with effects increasing with increased MICP productivity and duration of exposure. Similar trends were observed in samples exposed to ammonium salts, suggesting a likely mechanism of degradation. These results provide perspective on the limits and side effects of ureolytic self-healing and suggest paths toward optimization of MICP treatment medias for crack healing in OPC systems.

10:45am - Abstract #3522

Self-healing of cementitious materials containing hydrogels in seawater

Farzad Rezaeicherati and **Ali Ghahremaninezhad Ph.D**, University of Miami, Coral Gables, FL

Abstract Text:

This study examines the influence of internal curing technology on highway concrete bridge decks delivered through pre-saturated fine lightweight aggregates (FLWA) manufactured using landfill condition waste coal ash (LC-WCA). Guided by thermodynamic modeling and analytical calculations, LC-WCA was converted into lightweight ceramics referred to as LC-WCA-FLWA. These LC-WCA-based ceramics possess superior buoyancy characteristics, absorption capacity ($> 28\%$), desorption capacity ($> 40\%$), and sufficient compressive strength when compared to traditional FLWA (Stalite-FLWA) available in the market. Following Pennsylvania's bridge deck design criteria, concrete specimens were fabricated with a w/c ratio of 0.42, slump of 6 inches, and air content of 7 %. A comparative assessment was performed for concrete manufactured using LC-WCA-FLWA, Stalite-FLWA, and control concrete samples. The investigation assessed concrete's fresh properties, hardened properties, microstructure, and freeze-thaw durability. Results indicated that concrete manufactured with pre-saturated LC-WCA-FLWA required higher doses of plasticizer, similar air entrainment, and possessed lower fresh density than both Stalite-FLWA and control concrete specimens. Furthermore, LC-WCA-FLWA concrete demonstrated higher compressive strength achieving ~ 36 MPa after 56 days of curing, with a comparable flexural strength of 7.8 MPa, lower shrinkage by 33.5%, lower absorption rate, and lower freeze-thaw damage when compared to both Stalite-FLWA and control concrete specimens. Higher concentrations of calcium hydroxide (CH) were also found in LC-WCA-FLWA concrete indicating further cement hydration and optimum internal curing. This study's findings conclude that using pre-saturated LC-WCA-FLWA for the internal curing of concrete prompts higher concrete durability and service life performance.

11:00am - Abstract

Nano-modified aggregates and Methods for Durable Concrete

Xianming Shi, University of Miami; Jing Zhong, Harbin Institute of Technology, China; Jialuo He, Washington State University

Abstract Text:

This study presents a targeted nanotechnology-based strategy to enhance the performance and sustainability of cementitious composites by pre-treating fine and coarse aggregates with graphene oxide (GO) nanosheets. Recognizing that the interfacial transition zone (ITZ) between aggregates and cement paste is a key vulnerability, given its elevated porosity, we hypothesize that GO-modified aggregates can mitigate these microstructural weaknesses. GO was applied to both fine (sand) and coarse (gravel) aggregates via a presaturation method followed by drying, using a GO solid content of 0.02% by weight of cement. This patent-pending, scalable GO@aggregate approach offers a promising pathway toward more durable, lower-carbon concrete infrastructure.

The experimental results demonstrated significant mechanical and durability enhancements. In cement mortars with a cement-to-sand mass ratio of 1:3, GO-treated sand led to a 39.7% increase in 28-day compressive strength and a 68% reduction in gas permeability, reflecting a denser, more refined microstructure. BSE imaging and EDS analysis confirmed that the GO@sand treatment reduced both the porosity and thickness of the ITZ and promoted more uniform hydration products. Improvements were

confirmed in concrete specimens incorporating GO-modified sand and gravel at a w/c ratio of 0.40, with their 28-day compressive strength increased by 32% and water absorption decreased by 30%. Notably, these improvements were achieved with a 25.2% reduction in cement usage, contributing to significant decarbonization potential.

11:15am - Abstract #3512

Internal curing of 3D-printed bendable cementitious composites: A path to enhanced durability and crack resistance

Tayyab Zafar and Maryam Hojati, University of New Mexico, Albuquerque, NM

Abstract Text:

The construction of durable concrete infrastructure in arid regions faces significant challenges due to limited water availability and harsh environmental conditions. This study explores the feasibility of using lightweight aggregates (LWA) for internal curing in 3D-printed engineered cementitious composites (ECC) to address these challenges. River sand was partially replaced with pumice LWA at 30% and 60% volumes, while cement was replaced with 50% slag to enhance sustainability. Polyethylene (PE) fibers (2% by volume) were incorporated to improve mechanical properties. Pumice aggregates were presoaked for 24 hours and used as internal curing agents to evaluate their impact on printability and mechanical performance. Three mixes—S50-CT (control), S50-P30, and S50-P60 (pumice-modified)—were designed and printed using a 3D gantry printer. Specimens were cured under varying relative humidity conditions (18%, 75%, and 100%) at $25 \pm 1^\circ\text{C}$ for 28 days. Results showed that the addition of methylcellulose (MC) and PE fibers reduced extrudability but improved buildability, with the control mix exhibiting the highest buildability. The maximum compressive strength of 87.8 MPa was achieved for cast S50-P60 at 100% RH, while printed specimens reached 68.9 MPa for S50-CT at 100% RH. Pumice-modified printed mixes (S50-P30 and S50-P60) demonstrated strengths of 66 MPa and 64 MPa, respectively, highlighting the effectiveness of internal curing. Flexural performance improved significantly, with pumice-modified mixes showing higher peak loads and displacements, particularly at 100% RH. Maximum displacement of 7.44 mm was observed for S50-P60 (100% RH), compared to 3.2 mm for S50-P30 (18% RH). Internal curing ensured sustained hydration, enhanced microstructural integrity, and improved crack resistance, leading to greater durability.

11:30am - Abstract #3650

Interfacial degradation mechanisms in fly ash-blended low-heat cement concrete under thermal gradient effects

Haoyu Zeng, Ming Jin and Jiaping Liu, Southeast University, Nanjing, China

Abstract Text:

The integration of low-heat cement (LHC) and fly ash (FA) offers potential for sustainable construction, yet the durability of such systems under cyclic thermal loads remains underexplored. This study systematically evaluates the thermal fatigue resistance and microstructural evolution of LHC and ordinary Portland cement (OPC) concretes with FA (0–50%) subjected to 1200 thermal cycles. Multi-scale analyses—including compressive strength, ultrasonic pulse velocity, mass loss, in-situ nano X-ray computed tomography, and nanoscratch testing—reveal critical interactions between cement type, FA dosage, and degradation mechanisms. LHC exhibits superior initial strength and interfacial transition zone (ITZ) integrity due to dense hydration products and dispersed microcrack formation under thermal stress. However, its performance declines sharply at FA dosages >30%, as unreacted particles exacerbate ITZ porosity and interfacial debonding. In contrast, OPC benefits from FA's pozzolanic activity at $\leq 30\%$ FA, which refines ITZ pore structure and reduces stress concentration, yielding a 2.61% early

strength gain. Beyond 30%, FA weakens cohesion via unhydrated residues, accelerating strength loss. Distinct damage patterns emerge: OPC develops concentrated through-cracks, while LHC forms fine, dispersed microcracks that enhance crack resistance. Nanoscratch tests further show FA enhances ITZ micromechanics in OPC but acts primarily as a filler in LHC due to limited reactivity in low-alkalinity conditions. Random Forest analysis identifies ITZ width as the dominant factor (31% contribution) governing compressive strength loss, following an exponential decay model. Optimal FA dosages—30% for OPC and $\leq 10\%$ for LHC—balance thermal durability and interfacial performance.

11:45am – Brunauer Award

From selective dissolution to crystal chemistry of brownmillerite in sulfate resisting cement

Alexis Mériot^{1,2}, Marie-Noëlle de Noirfontaine¹, Mireille Courtial^{1,3}, Laurent Izoret², Sandrine Tusseau-Nenez⁴, Sébastien Diliberto⁵, Mélanie Labourel^{1,2}, Sandrine Gauffinet⁶ and Frédéric Dunstetter¹ (1) Ecole Polytechnique, Institut Polytechnique de Paris, (2) Syndicat Français de l'Industrie Cimentière, Clichy, France, (3) Université d'Artois, Béthune, France, (4) Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France, (5) Université de Lorraine, Metz, France, (6) Université de Bourgogne Franche-Comté, Dijon, France

Abstract Text:

The aim of this study is to extract brownmillerite from sulfate resisting Portland cement (SRPC) in order to determine its crystal chemistry and the effects of dissolution protocols. Brownmillerites (C_4AF) from four SRPC were extracted and systematically studied by X-ray diffraction (XRD), electron probe microanalysis (EPMA), and X-ray fluorescence spectroscopy.

Two extraction steps were used. The first is the salicylic acid/methanol (SAM) protocol that leaves a residue rich in ferrite, C_3A and sulfates. Precipitated hydrated sulfate minerals are also observed for clinker with high molar SO_3/Na_2O_{eq} ratio. The second, developed in this paper, uses acetic acid (AcA) extraction to dissolve C_3A and sulfates.

The Rietveld refinements showed that all brownmillerites of this study crystallize in *Im2* space group. Two families of brownmillerite were identified by their aluminum content and cell parameters, related to the presence of C_3A in the clinker. EPMA indicated that ferrites from SR0 and SR3 cements have Al/Fe ratios about 0.7 and 0.8–1.0, respectively. XRD allows to predict the $(Al+Mg+Si)/Fe$ ratio in brownmillerite in good agreement with EPMA. The SAM protocol is the best way to study crystal chemistry of brownmillerite and the AcA protocol is recommended to dissolve sulfates and C_3A for further reactivity studies.

C: Bio-Inspired Cementitious Materials

Wednesday, June 11, 2025, 1:45pm - 3:45pm

1:45pm - Abstract #3494

Mechanistic insights into engineering biomolecules' structure with surfactant for a novel air-entraining admixture in concrete

Sadegh Tale Masoule and Ali Ghahremaninezhad Ph.D, University of Miami, Coral Gables, FL

Abstract Text:

Concrete durability has been a critical aspect of construction engineering, especially in the context of freeze-thaw resistance. Recent advancements in material science have explored the incorporation of biomolecules as additives in cement paste to enhance its durability. Building upon this foundation, our study aims to investigate the potential of denaturing chemicals, namely lignin, sodium dodecyl sulfate (SDS), and urea, in modifying the protein structure and improving its properties as air-entraining admixtures. To achieve this objective, we conducted a series of experimental investigations using different protein samples in conjunction with varying concentrations of denaturing chemicals. The protein samples utilized in this study were selected based on their potential to enhance concrete performance, as previously established in our research on proteins in cementitious systems. By introducing lignin, SDS, and urea into the protein-cement paste system, we sought to exploit their denaturing properties to induce structural modifications in the protein and subsequently enhance its air-entraining characteristics. The evaluation of the modified protein-cement paste systems involved a comprehensive set of analyses. The change in protein structure was studied through a series of physico-chemical experiments, including surface tension and foaming, hydrodynamic size measurements and protein electrostatic charge. Additionally, we conducted extensive physical and mechanical property tests, including air-void analysis, liquid sorptivity, fluidity measurements, freeze-thaw resistance, and hydrophobization of the matrix. Results demonstrate that the introduction of denaturing chemicals induces notable changes in the protein structure. These structural modifications positively influenced the air-entraining capacity of the protein-based concrete, as observed through improved air-void characteristics. Furthermore, the incorporation of denaturing chemicals showed a promising impact on the freeze-thaw resistance of the concrete.

2:00pm - Abstract #3537

Rapid extraction & binding assessment techniques for the optimization of biomass-stabilized earth concrete

Samuel J. Armistead, Rebecca A. Mikofsky, and Wil V. Srubar III, University of Colorado Boulder, Boulder, CO, and Yierfan Maierdan and Shiho Kawashima, Columbia University, New York City, NY

Abstract Text:

With the shift towards a bio-based economy, there is a great interest in bio-inspiration and biomimicry to produce materials with low carbon, energy, and material inputs. Bio-stabilized earthen construction has gained recent attention as a sustainable and circular construction method. Waste biomass is of particular interest as a scalable and sustainable source of bio-stabilizers. However, fully exploring the composition-structure-property relationships between biomass and commonly occurring earthen minerals requires the development of new high-throughput experimental tools. This presentation will explore preliminary experimental data towards this vision, while also highlighting the potential of biomass-stabilized earth concrete as a new class of sustainable construction materials.

2:15pm - Abstract #3535

Disorder in tough cortical-bone inspired design of cement-based materials

Reza Moini and Shashank Gupta, Princeton University, Princeton, NJ

Abstract Text:

Statistical mechanics provides a powerful tool to capture and quantify order in arrangements of heterogeneous natural or bio-inspired engineered architected materials and, therefore, provides a unique lens toward the computational design of materials and structures. However, these powerful methods to quantify a spectrum of order-to-disorder arrangements have rarely been used in the domains of bio-inspired design of materials. Here, “*Disorder*” curves and statistical mechanics parameters (radial distribution function known as $g_2(r)$, translational order parameter (T), and orientational order parameter (Q), are proposed for the first time to quantitatively and characterize the degree of disorder for describing the representation of the architected arrangement of materials in lieu of otherwise inadequate “*periodicity*” classification and misperceived disorder parameters (perturbation and Voronoi tessellation methods). This approach can help formalize a quantifiable metric into the design of materials arrangement (solid or pore) and assist in performing inverse design of engineered phases of arrangement. From a statistical mechanics perspective, two limits of random (ideal gas) and perfectly ordered (Face-centered cubic (FCC) crystal) can be constructed with a “*disorder*” spectrum in between (0-to-1).

The approach was extended to understand cortical bone-inspired cement-based materials whereby design of disordered arrangements were examined using T, Q, and $g_2(r)$, against theoretical LEFM and experimental methods. We demonstrate the competition between tube size and shape on stress intensity factor from which engineering stepwise cracking can emerge.

2:30pm - Abstract #3596

Fracture mechanics of tough and ductile architected nacre-like cementitious composites

Shashank Gupta, Hadi Shagerdi Esmaeeli and Reza Moini, Princeton University, Princeton, NJ

Abstract Text:

Conventional cementitious materials exhibit limited energy absorption and resistance to fracture, making them prone to sudden, catastrophic failure. Hence, enhancing the fracture toughness and ductility of brittle cementitious materials remains a challenge. Nature provides numerous strategies to enhance fracture toughness without sacrificing strength using the purposeful arrangement of the constituent materials into clever architectures. In this study, we introduce a “nacre-like” brick-and-mortar structure inspired by mollusk shells, achieved through laser processing and periodic tabulation of cement paste sheets laminated with limited elastomeric interlayers (polyvinyl siloxane). These “nacre-like” architected composites replicate the toughening mechanisms of tablet sliding and interlayer deformation found in natural nacre – mechanisms that are typically absent in human-made brittle and quasi-brittle materials like cement paste and concrete. By precisely engineering laser-induced defects and tabulated arrangements of hard-soft materials, we activate interlayer deformation, tablet sliding, and tortuous crack propagation guided by the defects, leading to a significant enhancement of 17.1-fold in fracture toughness and 19-fold in ductility compared to brittle cement paste. These mechanisms also result in rising resistance curves in the “nacre-like” composites, contrasting with the flat brittle response of monolithic cement paste. The insights from this research offer a pathway to improving the toughness of cementitious materials by leveraging intentional flaws and incorporating small amounts of soft hyperelastic materials. This approach could lead to generating flaw-tolerant and impart crack-resistant characteristics in brittle cementitious material at a large scale, for example, employing large-scale lamination or additive manufacturing techniques.

2:45pm - Abstract #3622

Influence of waste bovine bone on hydration kinetics, mechanical, and microstructural behavior of portland cement

Lamiya Noor and Wil V. Srubar III, University of Colorado Boulder, Boulder, CO

Abstract Text:

This study examines the influence of bovine bone (BB) waste (which contains a significant proportion of naturally synthesized calcium hydroxyphosphate), industrially synthesized calcium hydroxyphosphate (HAp), and calcium hydrogen phosphate (CaHPO_4) as partial replacements for Portland cement. BB waste, HAp, and CaHPO_4 were used at 0%, 0.1%, 0.5%, 1%, and 2% replacement by weight of cement while maintaining a constant water-to-binder ratio. Hydration kinetics, as well as initial and final setting times, were evaluated using isothermal calorimetry. Mechanical performance was assessed through compressive strength measurements, while microstructural investigations were conducted using thermogravimetric analysis (TGA) and X-ray diffraction (XRD). Additionally, a dynamic stirred solution-solid interaction experiment was performed for 3 hours and 24 hours to examine changes in pH, mass loss, and elemental composition (Ca and P) when phosphates were exposed to a simulated pore solution. Results indicated that the investigated replacement levels of BB waste, HAp, and CaHPO_4 exhibited similar hydration kinetics to Portland cement. However, a decrease in 28-day compressive strength was observed when BB replacement levels exceeded 0.1%. This reduction was primarily attributed to the dissolution of organics from BB in cementitious systems, as evidenced by a pH reduction, mass loss of BB after dissolution in the simulated pore solution, and lower CH (portlandite) formation. No additional crystalline phases were detected in XRD at the investigated calcium hydroxy and hydrogen phosphates replacement levels. These findings suggest that waste BB can partially replace Portland cement (up to 0.1%) while maintaining comparable hydration, mechanical, and microstructural performance.

3:00pm - Abstract #3657

The impacts of silane functionalized hydrogels on early-age nucleation and growth of cement hydrates

Akul Nimish Seshadri, John A Howarter, and Kendra A. Erk, Purdue University, West Lafayette, IN

Abstract Text:

Hydrogel-based superabsorbent polymers (SAPs) have been researched over the last two decades for internal curing and self-healing concrete. However, most of the conventional hydrogels studied are purely organic and do not participate directly in cement hydrate growth beyond supplying water and localizing ions. To address this, we synthesized composite hydrogels functionalized with an alkoxysilane, whose silicate functionality enhances their role in hydrate nucleation and growth. Composite gels were investigated for their ability to react with cementitious mixtures and promote the growth of calcium silicate hydrate (C-S-H). Hydrogels were characterized through FTIR, gravimetric swelling tests, and scanning electron microscopy as synthesized and in cementitious environments such as pore fluid and cement paste. Uniquely, flash-frozen samples imaged in CryoSEM allowed for direct observation of hydrate formation and morphology at ages as early as 3, 18, and 21 hours of cement hydration. Conventional hydrogels in cement paste exhibited growth dominated hydrate formation at early ages and macrovoid formation at later ages. Conversely, silane containing hydrogels dissolved in alkaline cementitious mixtures, diffused into cement paste, and nucleated various morphologies of C-S-H. Furthermore, silane containing hydrogels contributed to microstructural refinement by facilitating nucleation dominated hydrate growth and reduced the overall volume of hydrogel-related macrovoids in the cement matrix. In this study we highlight the use of CryoSEM, an underutilized tool in cement research, to study early age interactions between a silane-functionalized organic additive and cement paste. Furthermore, this work

showcases the design of new, commercially scalable, hydrogel compositions for next generation internal curing and seeding agents.

D: Computational and Data Driven Materials Science

Wednesday, June 11, 2025, 1:45pm - 3:45pm

1:45pm - Abstract #3453

Phase transformation of nash gel under different enhanced geothermal system environments

Yangwoo Lee and Claire E. White, Princeton University, Princeton, NJ

Abstract Text:

This study addresses the challenges of developing carbon-neutral, cost-effective and durable cement formulations for enhanced geothermal systems (EGS) by focusing on low-Ca alkali-activated materials (AAMs) as a sustainable alternative to conventional well cements. Here, we investigate the formation and molecular structure of sodium-alumino-silicate-hydrate (N-A-S-H) gel, the primary binding phase in low-Ca AAMs, utilizing molecular dynamics (MD) simulations. Moreover, the impact of high temperature and high pressure (i.e., geothermal conditions) on the stability of N-A-S-H gel and any associated phase transformations has been evaluated using both experiments and simulations. Initial simulations focus on evaluation of force field parameters and specifically those associated with ReaxFF, with a particular emphasis on replication of known structural attributes of N-A-S-H gel such as Q^n speciation and aluminum coordination. Total scattering and associated pair distribution function (PDF) analysis has been employed to assess the validity of the N-A-S-H gel structural representation. Subsequent simulations have been performed to assess the impact of high temperature and high pressure on the molecular structure of N-A-S-H gel, where complementary experimental PDF data has been obtained after subjecting the gel to hydrothermal conditions. Additional experiments have been carried out on calcium and carbonate containing systems, where the influence of these ions on phase formation behavior has been uncovered. Overall, this research not only deepens our understanding of the N-A-S-H gel formation and behavior but also lays the groundwork for designing specialized cement formulations optimized for the demanding conditions of EGS operations. The insights derived from this study are expected to drive innovation in eco-friendly construction materials, enhancing durability and long-term cost-effectiveness while minimizing the environmental footprint.

2:00pm - Abstract #3560

Effects of nanoconfinement on salt crystallization

Luis A Ruiz Pestana, University of Miami, Coral Gables, FL

Abstract Text:

Salt crystallization within the small pores of natural stone or concrete can generate expansive pressures that exceed material tensile strength, leading to damage. While traditional thermodynamic models are generally accurate for larger pores, their assumptions fail under nanoconfinement, where anomalous transport, chemical reactions, and phase transitions prevail, as observed in various fields. In concrete, nanopores (<10 nm), particularly gel pores in the C-S-H phase, constitute a significant fraction of the pore volume, especially in UHPC, and play a crucial role in material performance. A deeper understanding of nanoconfinement effects on salt crystallization is essential for predicting the onset and severity of damage and developing mitigation strategies. This talk will present microsecond-scale molecular dynamics simulations of NaCl crystallization in slit nanopores of varying sizes. Our results show that salt solubility is significantly reduced, and crystallization kinetics are enhanced under nanoconfinement compared to the bulk. Additionally, we find that the nucleation and growth mechanisms are governed by the initial supersaturation of the solution and do not conform to classical nucleation theory. Our results challenge

the ability of approaches based on classical thermodynamics to predict material damage from salt crystallization in nanopores.

2:15pm - Abstract #3582

Modeling the corrosion of steel casing and the damage of well cement in a borehole system

Linfei Li, Florida International University, Miami, FL

Abstract Text:

Over the past 20 years, more than 100 projects have successfully injected CO₂ into underground reservoirs. Following injection, CO₂ may migrate upward or laterally due to subsurface pressure imbalances. Ensuring the long-term stability of injected CO₂ requires a thorough understanding of the mechanical properties of cement in the borehole system. This modeling study investigated the chloride-induced corrosion in an underground borehole system, focusing on steel casing degradation and its impact on surrounding cement. High chloride concentrations progressively compromise the functionality and durability of well cement, leading to potential gas and liquid leakage. A chemo-mechanical coupling diffusion model and a classical fracture mechanics model are employed. Validation is conducted using OPC concrete data from the literature before applying the model to well cement with experimentally obtained material properties. By predicting crack initiation, peak pressure, and complete fracture, the model quantifies the expected service life of the borehole system.

2:30pm - Abstract #3591

Phase-field cohesive zone crack propagation model for layered hard-soft architected materials

Aimane Najmeddine and Reza Moini, Princeton University, Princeton, NJ

Abstract Text:

Additively manufactured cement-based materials exhibit complex fracture behaviors including crack deflection, penetration, and bridging under various loading conditions due to the presence of interfaces between inherent constituents. Such dissipation mechanisms significantly impact mechanical properties (i.e., strength and toughness), ultimately leading to varying performances at large-scale. A critical challenge in designing additively manufactured assemblies is understanding how interfacial cohesion between constituent materials contributes to the overall mechanical properties and structural performance. In this work, we propose a fracture mechanics-based constitutive framework to elucidate the role of interfaces in both capturing and engineering the fracture response of additively manufactured cement-based materials. This framework integrates the phase-field approach to fracture with a Cohesive Zone Model (CZM), enabling the capture of various fracture propagation mechanisms both within the bulk material and across layered interfaces. Our research demonstrates that this framework accurately predicts a range of fracture dissipation phenomena in both brittle layered hard-hard cement-based assemblies and hard-soft composites with interfaces. These mechanisms include crack deflection and penetration in hard-hard assemblies, and crack bridging in hard-soft assemblies, along with additional toughening mechanisms such as progressive layer failure. Understanding these phenomena is crucial for designing resilient additively manufactured materials and large-scale structures.

2:45pm - Abstract #3659

Micromechanics-based poro-elastoplastic-damage model for concrete incorporating superabsorbent polymer (SAP)

Aiqing Xu, Georgia Institute of Technology, Atlanta, GA, and Xiaoyan Man and Jiann-Wen Woody Ju, University of California, Los Angeles, Los Angeles, CA

Abstract Text:

Superabsorbent polymer (SAP) has been effectively utilized to enhance the durability and functionality of concrete; however, the influence of SAP incorporation on the mechanical behavior and damage response of concrete remains incompletely understood. Incorporating the effects of pore pressure induced by SAP particles in different states (saturated, unsaturated, and void), this paper proposes a novel micromechanics-based poro-elastoplastic-damage constitutive model for SAP-incorporated concrete. By coupling the damage evolution caused by external stress with the internal pore pressure induced by SAP, the model effectively captures the synergistic interaction between these factors on the damage response and stress-strain relationship of concrete. The reliability and applicability of the proposed model are validated through comparisons with experimental data. With this model, the influences of SAP addition ratio and material properties on the damage response and mechanical performance of SAP-incorporated concrete are revealed. The results indicate that higher SAP addition ratios and larger particle sizes weaken the damage resistance and mechanical performance of concrete, while SAP voids with certain mechanical properties mitigate the development of internal damage and enhance overall performance. Therefore, it is essential to optimally determine the SAP addition ratio and material parameters based on application requirements. The proposed model provides a theoretical basis for optimizing the application of SAP in cement-based materials and can be extended to other cement-based materials with a porous matrix, demonstrating good potential for engineering applications.

3:00pm - Abstract #3370

Enhancing concrete durability and sustainability: Investigating carbonic anhydrase for corrosion resistance and self-healing in cementitious matrices

Nima Rahbar and **Sara Heidarneshad**, Worcester Polytechnic Institute, Worcester, MA

Abstract Text:

Concrete, the most widely used construction material, accounts for 8% of global CO₂ emissions, with corrosion significantly limiting its lifespan. This study investigates the use of Carbonic Anhydrase (CA), a bioenzyme, as a cost-effective corrosion inhibitor and durability enhancer in cementitious matrices. Concrete specimens with varying CA dosages (Control, CA-1X, CA-5X, CA-10X, CA-20X) were subjected to accelerated corrosion and permeability tests. Results show that CA-5X reduced rebar corrosion depth by 34% and delayed crack initiation by 24 hours, demonstrating superior corrosion resistance. Water permeability tests revealed a 50% reduction in dye penetration, indicating improved resistance to chloride ion ingress. Microstructural analysis (TGA, MIP, and μ -CT) confirmed CA-induced crystal precipitation and pore refinement, enhancing concrete durability. Additionally, numerical diffusion simulations provided insights into transport mechanisms, while Life Cycle Assessment (LCA) highlighted environmental benefits. These findings suggest that CA-modified concrete offers a promising, sustainable solution for extending service life and reducing repair needs, mitigating concrete's environmental impact.

E: Material Characterization Techniques

Thursday, June 12, 2025, 10:00am - 11:45am

10:00am - Abstract #3394

Is there a future for ^{43}Ca nuclear magnetic resonance in cement science?

Franco Zunino, University of California, Berkeley, Berkeley, CA, Ziga Casar, Princeton University, Princeton, NJ, Davide Tisi, EPFL, Lausanne, Switzerland, and Samuel J Page and Chris Greenwell, Durham University, Durham, United Kingdom

Abstract Text:

Calcium and silicon are critical components of cement. While ^{29}Si nuclear magnetic resonance (NMR) is widely used in cement science, ^{43}Ca NMR has received comparatively less attention given the experimental challenges associated with it. To investigate the potential of ^{43}Ca NMR in cement research, a density functional theory study was carried out. The study focused on distinct calcium sites within the calcium silicate hydrate (C-S-H) structure. Four unique calcium sites were identified, each predicted to display distinct ^{43}Ca chemical shifts due to differences in their local environments. These findings were used to generate theoretical ^{43}Ca NMR spectra for C-S-H. Furthermore, theoretical ^{43}Ca NMR spectra for the hydration reaction of triclinic tricalcium silicate were developed, illustrating the potential of ^{43}Ca NMR for tracking the hydration process in multiphase systems.

10:15am - Abstract #3441

Deploying computer vision for rapid sorptivity testing

Hossein Kabir, Sunav Raj Dahal and **Nishant Garg**, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

Sorptivity, the rate at which water infiltrates unsaturated cement-based materials, is a key indicator of potential deterioration. One widely used protocol to measure sorptivity is ASTM C1585, which involves submerging specimens and tracking water absorption over time. However, this approach is labor-intensive, relies on manual measurements, and typically spans multiple hours or even days. Lengthy durations are problematic for quality control due to greater opportunities for human error and design efficiency. This study introduces two computer vision-based methods that accelerate sorptivity and correlate their outcomes with freeze-thaw performance, surface resistivity, and RCPT indices. The first “droplet” method analyzes the contact angles of water droplets on cement paste surfaces to link droplet-wetting behavior to sorptivity. The second “waterfront” method employs an algorithm that tracks the advancing waterfront to compute initial and secondary sorptivities from wetted area ratios. Trained on extensive image datasets, these methods deliver real-time, high-accuracy sorptivity predictions ($R^2 > 0.9$) and align well with standard durability evaluations.

10:30am - Abstract #3499

Probing the nanoscale pore structure of alkali-activated metakaolin using electron microscopy and novel neutron techniques

Anita Zhang and Claire E. White, Princeton University, Princeton, NJ

Abstract Text:

Conventional characterization of the pore structure of cement-based materials typically involves measurement of the pore size distribution using gas sorption or mercury intrusion, while other techniques

include ^1H NMR and small angle scattering. Although these techniques provide crucial insight on the size of pores they fall short of being able to fully determine the 3D pore structure. Here, we explore the capabilities of two novel neutron techniques, neutron grating interferometry (nGI) and spin-echo small-angle neutron scattering (SESANS), in conjunction with focused ion beam scanning electron microscopy (FIB-SEM) to elucidate the 3D pore structure of alkali-activated metakaolin paste. For both nGI and SESANS the measured visibility datasets as a function of autocorrelation length provide insight on the size of pores (ranging tens to hundreds of nanometers) without the need for any sample pretreatment (i.e., drying), with the visibility from nGI being spatially resolved (i.e., pixel dependent in 2D). FIB-SEM, which provides a 3D pore structure representation of the paste, has been used to validate extracted pore information. Neutron instruments incorporating nGI and Bragg edge imaging that are currently under development will further expand on these non-destructive pore characterization capabilities by accessing pore information in 3D.

10:45am - Abstract #3503

Insight into cement paste chemical hydration being expansive through the shard test

Raul E Marrero, Tapiwanashe Bhibho, Gianluca Cusatis, and Zdeněk P Bažant, Northwestern University, Evanston, IL, and Ahmet A Dönmez, US Gypsum Co., Livertyville, IL

Abstract Text:

Understanding volume changes in concrete during the hydration, self-desiccation, or moisture exchange has been a predominant question for many decades. The effect of these volume changes on structural element and within 3D-printed concrete needs to be understood to predict the durability of structures. Nanoporomechanics and Gibb's free energy models of cement past skeletons suggest that chemical hydration should produce expansion. This idea contradicts the common perception that chemical hydration causes shrinkage. According to ASTM C1608 — Standard test method for Chemical Shrinkage of Hydraulic Cement — the cement paste of 7.5 to 10 mm in height, when submerged in water, should be a fully saturated system. However, due to the size, the analytical solutions show that achieving full saturation takes a long time. The test size creates a competition between expansion due to chemical hydration and shrinkage due to self-desiccation, which is ultimately what is measured. For large specimens, shrinkage caused by moisture movement (self-desiccation or drying) dominates the observation. The Shard test is a novel measurement technique that monitors volumetric change evolution over time of a 0.5 mm thick shards using the Olympus 3D Laser Confocal Microscope. Specimens aged 12 to 24 hours are cut with a precision diamond saw and then submerged in either deionized (DI) water or paraffin oil. Analytical calculations indicate that 0.5 mm samples reach full saturation within few hours, allowing for the decoupling of chemical hydration expansion from self-desiccation shrinkage. The results show that shards of cement paste with a water-to-cement (w/c) of 0.4, when fully saturated in DI water, exhibits expansion. In contrast, shards submerged in paraffin oil exhibit shrinkage due to self-desiccation. This test confirms predictions from 2015 analytical models.

11:00am - Abstract #3595

Geochemical fingerprinting of imported cements for supply chain transparency

Antonio T Skillicorn, Karrie Weaver, Tiziana Vanorio, Jonathan Payne and Sarah L Billington, Stanford University, Stanford, CA

Abstract Text:

U.S. cement imports are steadily increasing, with more than a quarter of domestic consumption now sourced from abroad. The supply chain for imported cement can lack transparency due to the involvement of third-party importers and numerous upstream suppliers of raw materials. As a result, verifying the environmental and labor impacts of raw material extraction is difficult. This study explores the use of geochemical fingerprinting to trace cement constituent material provenance and improve supply

chain transparency. We analyzed elemental concentrations and strontium isotopic signatures ($^{87}\text{Sr}/^{86}\text{Sr}$) in cement and corresponding limestone samples from 11 domestic plants (N = 22 samples) as a case study. Our findings show that trace element profiles can effectively distinguish cements from different sources, with Na, Mg, P, K, Mn, Ni, Cu, Zn, and Sr emerging as particularly variable signatures. This result highlights the potential for building a database of geochemically characterized samples, theoretically allowing cements of uncertain origin to be matched to reference materials. Additionally, we preliminarily identify that $^{87}\text{Sr}/^{86}\text{Sr}$ values in cement are consistently higher than in the corresponding source limestones and also exceed the primary seawater $^{87}\text{Sr}/^{86}\text{Sr}$ values associated with the ages of the source limestones. While additional data are needed, these trends appear systematic. To develop a more comprehensive fingerprinting and provenancing framework, additional isotope systems should be explored for linking cement with other key raw materials, including shale, gypsum, sand, and iron ore.

11:15am - Abstract #3632

Calcium hydroxide dissolution kinetics: Crystals and powders

Yoonjung Han and Jeffrey W. Bullard, Texas A&M University, College Station, TX

Abstract Text:

Calcium hydroxide ($\text{Ca}(\text{OH})_2$), also known as portlandite, is essential in various industrial applications, such as water treatment and food processing. In portland cement systems, it constitutes about 27% of the hydrated cement paste and participates in both beneficial and detrimental reactions during the concrete's service life. As a primary reactant in the pozzolanic reaction, calcium hydroxide is crucial for strength development. However, it is one of the first phases to leach from cementitious binders when exposed to water. Typically, calcium hydroxide forms relatively large hexagonal crystals within the microstructure of hydrated cement paste. Despite its significance, our understanding of the specific locations and mechanisms of dissolution on the surface remains limited. This study uses *in situ* Digital Holographic Microscopy (DHM) to directly observe localized surface changes, such as etch pit formation and step motion, both of which commonly happen in both dissolution and growth. Insights from this method can be applied to modeling the evolution of 3D microstructures after pozzolanic reactions and simulating microstructural changes due to prolonged leaching.

11:30am - Abstract #3444

Understanding the growth kinetics of cementitious magnesium silicate hydrates using atomic force microscopy

Carey Chang and Erika La Plante, UC Davis, Davis, CA

Abstract Text:

Alternative cementitious materials, such as magnesium silicate hydrate (M-S-H), address the need for sustainable cement production by reducing embodied CO_2 emissions and increasing durability. Precipitation rates and mechanisms of binding phases fundamentally control microstructural and property development in structural materials. Therefore, the kinetics of M-S-H nucleation and growth have become an active area of research; however, growth rates, underlying mechanisms, and transformation pathways remain poorly understood. In this study, M-S-H was grown on freshly cleaved magnesium oxide (MgO) substrates using magnesium nitrate hexahydrate and sodium metasilicate pentahydrate stock solutions, generating growth solutions containing $[\text{Mg}] = [\text{Si}] = 0.4$ to 30 mM. An atomic force microscopy (AFM)-based approach was developed to quantify growth rates of M-S-H at ambient temperature, including (1) initial (within 15 s) growth rates for varying saturation index (SI) relative to $\text{M}_{0.75}\text{SH}$ (-0.76 to 8.05) and (2) time-dependent (over 15 s to 3 weeks) growth rates for a fixed $\text{M}_{0.75}\text{SH}$ SI of 6.43. From the SI quantified

using geochemical modeling and the AFM-derived growth rates, the following rate equation was derived: $\ln(\text{rate}) = 0.31\ln(\text{SI}) - 19.87$ and interpreted according to geochemical and microstructural models of M-S-H formation. Experimental data yielded a power-law relationship between rate and SI, demonstrating thermodynamic control over growth rates and revealing a plateau indicative of surface-limited growth. Furthermore, high-resolution AFM data illustrated surface morphology evolution with increasing Mg/Si ratios, providing insight into heterogeneous M-S-H nucleation and growth on MgO. These findings provide a foundation for manipulating and refining mechanical, thermal, and chemical properties of M-S-H-based cement by inferring specific M-S-H phases from geochemical modeling. This study highlights the dependence of M-S-H growth kinetics on the evolving composition of the growth solution. Such understanding advances the fundamental knowledge of M-S-H as a durable, sustainable cementitious material while also supporting predictive modeling to improve its application.

F: Supplementary Cementitious Materials (Part 1 of 2)

Thursday, June 12, 2025, 10:00am - 11:45am

10:00am - Abstract #3414

Utilization of waste eggshell as a limestone alternative for high-volume incorporation in portland cement

Beng Wei Chong, Pratik Gujar, and Xijun Shi, Ingram School of Engineering, Texas State University, San Marcos, TX, and Prannoy Suraneni, University of Miami, Coral Gables, FL

Abstract Text:

The incorporation of waste eggshells in cementitious materials presents an innovative strategy to support the decarbonization of the cement industry. Eggshell powder exhibits properties similar to limestone; however, its performance in cement is often hindered by organic impurities and heterogeneous surface characteristics. This study investigates and optimizes the heat treatment of eggshells to enhance their performance, making them a viable limestone alternative. Characterization revealed that eggshell powder contains approximately 6% organic impurities by mass, primarily from the egg membrane. While these organic components have minimal impact at a 15% cement replacement level, they significantly influence cement performance at 35% replacement, imparting hydrophobic properties that compromise paste flow, clinker hydration, and mortar strength. Rheological analysis indicated that pastes containing untreated eggshell powder exhibited higher static yield stress but lower dynamic yield stress. Additionally, mortars with untreated eggshell powder showed greater shrinkage compared to those incorporating limestone powder. Heat treatment effectively denatured the organic content, mitigating these adverse effects. Beyond a treatment temperature of 300°C, mortars containing eggshell powder exhibited strength comparable to those with limestone. At 500°C, all organic influences that impaired flowability were eliminated, resulting in a hydrophilic behavior similar to limestone. Consequently, waste eggshells can be effectively valorized as a sustainable alternative for producing blended cement with up to 35% clinker replacement.

10:15am - Abstract #3439

Impact of sodium mordenite on carbonation rate and mineralogy of portland cement

Melissa Mills, Atolo A Tuinukuafe and Jessica M Rimsza, Sandia National Laboratories, Albuquerque, NM

Abstract Text:

To help reduce the reliance on energy-intensive cement clinker, supplementary cementitious materials (SCMs) are increasingly being used. Zeolite SCMs provide uniform porosities and chemical compositions for elucidating carbonation mechanisms in blended cement pastes. Work presented here investigates the incorporation of the zeolite mineral sodium mordenite (Na-MOR) in cement pastes and its effects on strength, carbonation rates, pore structure, and mineralogy. Portland cement pastes with 0%, 10%, 20%, and 30% replacement by weight of Na-MOR were prepared, hydrated and exposed to a 3% CO₂ environment for variable durations (up to 16 weeks) to evaluate carbonation. Strength properties were evaluated for noncarbonated and carbonated samples along with further characterization of compositional and mineralogical changes by quantitative x-ray diffraction (QXRD), gas adsorption, and scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS). Results indicate increasing mordenite content increases carbonation rates through diffusion driven processes due to increased tortuosity. The mineralogy of carbonated binders suggests Na-MOR additions can also promote recalcification of CaO from cement clinker as CaCO₃. Compressive strengths for uncarbonated 10% and 20% Na-MOR replacement cements. Additionally, a 70% increase in surface area is observed

upon carbonated Na-MOR pastes, indicating partial retention of the mordenite structure. These findings lend fundamental insight into carbonation mechanism of portland cement with SCMs and the long-term stability of Na-MOR in cementitious media. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525. SAND2025-02369A.

10:30am - Abstract #3466

Energy-positive, carbon-negative, reversible cementitious material for future infrastructure and clean energy transition

Jialai Wang and Maysam Bahmani, The University of Alabama, Tuscaloosa, AL

Abstract Text:

Ordinary Portland Cement (OPC)-based concrete, a cornerstone of modern infrastructure, is a major contributor to CO₂ emissions, resource depletion, and waste generation. OPC production accounts for 8% of global CO₂ emissions and consumes over 6 billion tons of raw materials annually, while concrete production uses 30 billion tons of aggregate and generates 2.2 billion tons of C&D waste yearly. This study introduces a novel manufacturing process that mitigates these impacts by utilizing waste streams as energy sources and raw materials while sequestering carbon as high-value carbon nanotubes (CNTs). The resulting cement will enable next-generation concrete for resilient, net-zero infrastructure and advanced technologies like structural health monitoring, renewable energy integration, and smart urban systems.

10:45am - Abstract #3501

Development of a cementless binder via carbonation application to fly ash

Jihoon Lee Mr., and Juhyuk Moon Prof, Seoul National University, Seoul, Korea, Republic of (South), and Franco Zunino, University of California, Berkeley, Berkeley, CA

Abstract Text:

In this study, a high-performance cementless binder was developed through the combination of triethanolamine (TEA) addition and carbonation curing of fly ash. The effect of TEA on the hydration and carbonation of fly ash was investigated at dosage of 1 and 5 wt%. In the absence of TEA, the reaction of fly ash was negligible. By contrast, the dissolution of merwinite in fly ash was enhanced with TEA content. Therefore, TEA significantly increased the solubility of fly ash, particularly calcium and aluminum due to its complexation effect, thereby enhancing the formation of both hydration and carbonation products. Without the introduction of carbonation, ettringite and monosulfate were the main hydration products, and their relative abundance depended on the TEA content; however, the compressive strength was similar for 1 and 5 wt% of TEA. Meanwhile, when carbonation curing was applied, C-A-S-H containing six-coordinated aluminum formed instead of monocarbonate and ettringite. Notably, spherical-shaped amorphous calcium carbonate was generated as a carbonation product rather than crystalline calcite, vaterite, or aragonite and remained stable for up to 7 days of carbonation. As a result, at 5 wt% of TEA, a significant refinement in pore structure was observed in carbonated fly ash paste and over 70 MPa of strength was achieved after 7 days of carbonation.

11:00am - Abstract #3520

Harnessing biocarb-driven carbonate-aluminate synergy for enhanced reactivity, strength, and carbon storage in low-carbon cementitious systems

Monica Amaral, Xiaodong Wang and Jialai Wang, The University of Alabama, Tuscaloosa, AL

Abstract Text:

The synergy between carbonates and aluminates in cementitious systems is well established, but the introduction of biomolecule-regulated CO₂ mineralization via the BioCarb method presents an additional dimension to this interaction. This study investigates how the presence of a biomolecule influences the reactivity of tricalcium aluminate (C₃A) and the stabilization of carboaluminate phases in a system incorporating BioCarb, metakaolin, and gypsum. Preliminary results indicate an enhancement in C₃A reactivity, leading to increased formation of stable carboaluminates and a more balanced sulfate-aluminate-carbonate equilibrium. Isothermal calorimetry reveals improved hydration kinetics after sulfate depletion, with mechanical performance tests showing up to a 25% improvement in compressive strength after 28 days. These findings suggest a potential pathway for optimizing blended cement formulations by leveraging controlled carbonate-aluminate interactions. Ongoing research aims to further elucidate the microstructural and thermodynamic implications of this approach, with broader implications for improving carbon storage and binder efficiency in low-carbon cementitious materials.

11:15am - Abstract #3643**CO₂ uptake in calcium aluminosilicate materials**

Subhashree Panda, Luis A Ruiz Pestana and **Prannoy Suraneni**, University of Miami, Coral Gables, FL

Abstract Text:

CO₂ mineralization has gained increasing attention as a strategy to reduce CO₂ emissions from concrete production. This approach not only mitigates environmental impact but can also enhance the mechanical properties and durability of cement-based systems. The extent and kinetics of carbonation are influenced by factors such as the availability of free CaO/MgO, hydration state, and CO₂ uptake conditions. This study investigates the carbonation potential of calcium aluminosilicate (CAS) systems as a proxy for supplementary cementitious materials and related materials. By varying the synthesis temperature from 1000°C to 1600°C, we synthesized a range of CAS materials, transitioning from partially crystalline to fully amorphous structures. Our findings indicate that compositions synthesized at 1000°C exhibited the lowest amorphous content and are least reactive but have the highest CO₂ uptake potential. In contrast, those synthesized at 1600°C were fully amorphous and highly reactive systems but showed minimal CO₂ uptake potential.

11:30am - Abstract #3477**Optimizing clay mineral dehydroxylation for energy-efficient supplementary cementitious material production: A kinetic and mechanistic approach**

Oluwadamilare Charles Adesina, Sayee Srikarah Volaity, and Narayanan Neithalath, Arizona State University, Tempe, AZ, Bryan K Aylas-Paredes and Aditya Kumar, Missouri University of Science and Technology, Rolla, MO, and Chengqing Qi, Ash Grove Cement Company, Overland Park

Abstract Text:

Reducing clinker content by incorporating supplementary cementitious materials (SCMs) is a key strategy for mitigating the 8 anthropogenic CO₂ emissions associated with cement production. Among SCMs, calcined clays—produced through the heat treatment of geologically abundant and cost-effective raw clays—play a pivotal role in low-carbon cement blends such as limestone-calcined clay (LC²) supplements and limestone-calcined clay cements (LC³). However, the lack of pre-requisite fundamental studies on clay dehydroxylation mechanism often leads to inefficient calcination protocols, with unnecessarily prolonged high-temperature treatments that compromise energy efficiency, material reactivity and the market viability of these cement blends. This study presents a robust kinetic analysis of

kaolinite and montmorillonite (notable for their pozzolanic properties) dehydroxylation under linear non-isothermal temperature programs, employing advanced model-free methods that are devoid of computational approximations to ensure reliable predictions across a suitable temperature range for clay calcination. Activation energy and pre-exponential factor components of the kinetic triplet characterizing the dehydroxylation reaction are determined using the Friedman differential and advanced Vyazovkin incremental isoconversional methods. The third component—the reaction model, identified using the master plot approach and kinetic compensation effect—reveals a reaction-order mechanism for kaolinite dehydroxylation, while montmorillonite exhibits a diffusion-controlled process from the crystallite perspective. The derived kinetic triplets are implemented to predict isothermal calcination conditions for the clay minerals, further validated through thermogravimetric (TGA) and X-ray diffraction (XRD) analyses. Additionally, the reactivity of the calcined clays is assessed using heat release rates of clay-portlandite blends from isothermal calorimetry within a thermodynamic framework. The developed framework provides a comprehensive foundation for optimizing calcination conditions of raw clays to maximize dehydroxylation, enhance reactivity, and improve energy efficiency while mitigating the risks of over-calcination in activated clays for sustainable cement replacements and/or cement manufacture.

G: Cement Chemistry (Part 1 of 2)

Thursday, June 12, 2025, 1:15pm - 3:00pm

1:15pm - Abstract #3442

Growth kinetics of magnesium silicate hydrate: Rates and mechanisms

Benetta MacAuley, University of California, Davis

Abstract Text:

Magnesium silicate hydrate (MSH) is a potential durable alternative to calcium silicate hydrate (CSH), a major component of Ordinary Portland Cement (OPC). The development of strength in concrete is fundamentally controlled by the rate and extent of precipitation of the cementitious binder. Therefore, to assess the use of MSH as an alternative binder in construction, further research into its precipitation rate is needed. In this study, MSH was grown in a mixed-flow reactor from reaction solutions containing $[Mg]=[Si]=10\text{mM}$. Aliquots of the residual growth solution were taken at reaction times ranging from 1 minute to 24 hours for analysis using inductively coupled plasma optical emission spectroscopy (ICP-OES) to quantify the precipitation rate of MSH from the concentrations of Mg and Si. Geochemical modeling was used to calculate the saturation index of the various phases of MSH that could form from the reaction solutions. In addition, the growth rate was investigated under various temperatures and additives to quantify the activation energy and reveal the mechanisms of MSH growth. Furthermore, insights into magnesium-based cementation is obtained from comparisons with CSH growth rates from literature and experiments. Characterization of the precipitated MSH is performed using acid digestion and synchrotron X-ray diffraction to quantify the Mg/Si molar ratio and the extent of growth congruency, and to characterize the crystallographic structure of the precipitate. Taken together, these results provide insights into optimizing MSH for magnesium-based cements.

1:30pm - Abstract #3460

The impact of RED MUD-derived layered double oxides (LDO) on hydration, microstructure, and properties of cement paste

Molan LI and Hailong Ye, The University of Hong Kong, Hong Kong

Abstract Text:

Red mud and MgO can be used as the combined source of metal oxides for synthesis of layered double hydroxide (abbreviated as RM-LDHs), which has been demonstrated to show great potential as chloride adsorbent and dye amendments. In this study, RM-LDHs were synthesized using the calcination-hydration method in two steps. First, a mixture of red mud and MgO was calcined at $650\text{ }^{\circ}\text{C}$ for 4 h to obtain the RM-LDHs precursor (referred to as RM-LDO). Then, RM-LDO was added to a salt solution and aged at $70\text{ }^{\circ}\text{C}$ for 48 h, yielding RM-LDHs with interlayer anions matching those in the salt solution. The aim of this study was to investigate the effect of RM-LDO on the hydration process, microstructural evolution, and properties of cement pastes, as well as to optimize its dosage. Additionally, this study explored the introduction of specific salts into the mixing water to evaluate whether RM-LDO can facilitate the in situ formation of RM-LDHs with specific anions during hydration. The influence of different RM-LDO dosages on the hydration process and microstructural development of cement pastes was analyzed using X-ray diffraction, thermogravimetric analysis, and Fourier transform infrared spectroscopy. The outcome of study can promote the upcycling of industrial waste as value-added construction materials, specifically provides a sustainable solution to waste management in the alumina refining industry while creating value-added products for the construction sector.

1:45pm - Abstract #3473

Impact of inter-grinding on the reaction kinetics and rheology of one-part alkali-activated metakaolin

Meddelin Setiawan and Claire E. White, Princeton University, Princeton, NJ

Abstract Text:

Developing alkali-activated materials (AAM) is one of the pathways to decarbonize cement manufacturing that currently contributes 5-8% of global anthropogenic carbon emissions. However, extensive deployment of AAMs in industry has yet to be realized, part of which is due to the reluctance to work with “two-part” activation that requires handling large amounts of concentrated caustic solutions. Here, we have developed a “one-part” AAM, where the dry mixture of precursor and activator is mixed with only water, resembling the hydration of OPC. Low-grade calcined kaolin clay (metakaolin) was chosen as the aluminosilicate precursor due to the high availability of low-grade kaolin clay, making it more commercially attractive than the lower availability sources of fly ash and blast furnace slag. The dry mixture was synthesized via inter-grinding in a planetary ball mill, which was found to increase the kinetics of alkali-activation and improve the rheology of the paste. The focus of this work was to investigate the underlying physiochemical properties responsible for the measured changes in reactivity and rheology, explored by analysis of particle size distribution, surface properties, nanostructure, and specific surface area. Hence, this work aids in deepening our understanding of the reaction mechanism of “one-part” alkali-activated metakaolin, and connects this insight with larger-scale performance characteristics which are central to actualization of design codes and standards for AAM.

2:00pm - Abstract #3669

Seeding effect of nano-ettringite on the hydration kinetics of tricalcium silicate C_3S , and ye'elimite $C_4A_3\$$ clinker phases

Rupack R. Halder, **Abdulkareem O Yusuf**, Ugochukwu Ewuzie and Monday U. Okoronkwo, Missouri University of Science and Technology, Rolla, MO

Abstract Text:

While the acceleration effects of nano-ettringite on cement hydration are well studied, limited research has explored its specific influence on the hydration kinetics of individual clinker phases at different curing conditions. This study employed dual-channel micro reaction calorimetry, X-ray diffraction, and thermogravimetric analysis to examine the seeding effect of nano-ettringite on the early hydration behavior of prominent clinker phases, including tricalcium silicate (C_3S), and ye'elimite ($C_4A_3\$$) at 10 °C, 25 °C, and 40 °C. Ettringite nano-seeding effectively accelerated hydration of C_3S , as demonstrated by faster heat evolution, increased cumulative heat release, and higher bound water loss within the hydration product decomposition temperature range. On the other hand, nano-seeding also accelerated ye'elimite hydration slightly at 10 °C, significantly at 25 °C but led to an overall decline in hydration rate beyond the initial stages of ye'elimite hydration at 40 °C. By acting as a nucleation site, nano-ettringite is projected to enhance hydration kinetics and influence the dissolution rates of these phases. This study provides a deeper understanding of the phase-specific effects of nano-ettringite at varying curing conditions of temperatures, offering potential strategies and pathways for optimizing cement hydration.

2:15pm - Abstract #3618

Cavalcade mechanisms for gaseous mineralization in portland cement

Atolo A Tuinukuafe and Jessica M Rimsza, Sandia National Laboratories, Albuquerque, NM

Abstract Text:

Portland cement has been widely used in the construction industry as a hydraulic binder that reacts with water to form calcium silicate hydrate (C-S-H) as the main strengthening phase. However, more volumetrically stable binding phases, like calcite, can form when portland cement is cured with gaseous CO₂ and water vapor. Gaseous curing could be used to produce high-performance cement composites, but diffusion and reaction mechanisms have limited its efficiency. In this study, a cavalcade analogy is proposed for mechanisms that enable efficient gaseous mineralization in portland cement through enhanced gas diffusion and clinker reactions. The accuracy of this analogy for mineralization mechanisms was tested by using various zeolite additives in gaseous cured portland cement. The pore structure and chemical composition of zeolites was correlated to the efficiency of gaseous mineralization with reaction kinetics, C-S-H stoichiometry, and calcium carbonate concentrations as key metrics. Techno-economic analysis and life cycle cost analysis were performed to evaluate the industrial implications of the proposed cavalcade mechanisms in cement-based composites. *SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.*

2:30pm - Abstract #3661**Enhanced CO₂ sequestration and strength of cementitious materials using a cost-effective renewable admixture**

Aniket Patnaik, Jialai Wang and Monica Amaral, The University of Alabama, Tuscaloosa, AL

Abstract Text:

CO₂ mineralization presents a promising pathway for sequestering CO₂ in concrete, enhancing its performance, and reducing its carbon footprint. This study explores a cost-effective, naturally occurring molecule as a renewable admixture to regulate CO₂ mineralization in cement slurry. The aim is to enhance CO₂ uptake while controlling the formation of carbonation products. Preliminary evaluation of mortar samples prepared with this approach demonstrated significant improvements in workability and mechanical properties, with compressive strength increases of up to 46% after seven days. These findings suggest that regulating the mineralization process with a small-dose admixture is a promising strategy for boosting binder efficiency and reducing clinker demand in sustainable concrete production. Ongoing research aims to further elucidate the microstructural evolution of materials produced through this innovative approach.

2:45pm - Abstract #3567**Enhancing the reactivity of belite via foreign dopants**

Hyeonseok Jee and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

Given the high carbon footprint of ordinary Portland cement production, reducing its environmental impact is a key priority for the construction industry. Belite (dicalcium silicate, C₂S) cement offers a promising alternative, but its low reactivity remains a challenge. This study examines the effects of foreign dopants on the structure and hydration reactivity of C₂S. Doped C₂S powders were synthesized via calcination and characterized using X-ray diffraction and Raman spectroscopy, confirming β-C₂S stabilization. Rietveld refinement indicated lattice expansion due to dopant incorporation. Hydration kinetics monitored by isothermal calorimetry showed a fourfold increase in cumulative heat evolution for doped C₂S (~80 J/g) compared to pure C₂S (~23 J/g), demonstrating enhanced reactivity. These findings provide insight into dopant-induced modifications in C₂S, contributing to the development of more reactive belite cements for sustainable construction.

H: Sustainability (Part 1 of 3)

Thursday, June 12, 2025, 1:15pm - 3:00pm

1:15pm - Abstract #3378

A foundation for zero emissions: Low-energy, carbon-absorbing cement

Matthew Watson and Matthew Cowan, University of Canterbury, Christchurch, New Zealand, Chris Bumby, Victoria University of Wellington, Wellington, New Zealand, and Murray McCurdy, Te Pū Ao, Wellington, New Zealand

Abstract Text:

Portland cement, accounts for 8% of total global greenhouse gas emissions, primarily through CO₂ released during production. While various alternatives are under development to reduce CO₂ emissions, a competitive replacement has yet to be realised.

Our research aims to develop an iron-based cement that sequesters CO₂ and can replace Portland cement. The iron-based cement we are researching was initially developed in the USA (Ferrock) and cures based on the carbonation of iron with CO₂ and water. However, the existing Ferrock process relies on waste iron dust material with embodied carbon emissions to be economic, thereby limiting scalability. Our approach to overcoming this scalability issue is to produce iron particles directly from titanomagnetite ironsands as a replacement for iron dust. This is based on a hydrogen reduction process that has been developed over the past 5 years.

The reaction pathway of the hydrogen direct reduction of New Zealand's titanomagnetite ironsands will be presented. An overview of the form, particle size distribution, and phases present will be given, alongside our initial experimental results for curing cement made with the particles. The economics of replacing the waste iron dust in the original Ferrock formulations with hydrogen-reduced iron particles will be compared.

1:30pm - Abstract #3475

Numerical simulation of heat transfer and calcination kinetics in a novel low-temperature limestone calcination approach

Sayee Srikarah Volaity, Oluwadamilare Charles Adesina, Shubham Agrawal, Md Sayeed Faisal, and Narayanan Neithalath, Arizona State University, Tempe, AZ, and Aditya Kumar, Missouri University of Science and Technology, Rolla, MO

Abstract Text:

The calcination of limestone (CaCO₃) at ~900°C producing lime (CaO) serves as an important precursor in cement manufacture. This calcination reaction accounts for ~50% of the CO₂ emissions, and ~15% of the total energy demand of the cement production process. Therefore, in this study we evaluate a novel low-temperature calcination process based on self-propagating high-temperature synthesis (SHS). SHS utilizes exothermic heat generated by the combustion of fuel mixed with the reactants to drive the calcination reaction, thereby enabling calcination at half the temperatures (~450°C) required for conventional calcination, leading to potential reductions in energy consumption. Since the application of SHS for calcination is relatively new, it is critical to understand the effects of different process variables on the calcination extent and the kinetics for optimizing the throughput. In this regard, heat-transfer simulations are carried out on pellets with varying fuel contents, sizes, and porosities, which are also validated using experimentally determined surface temperature profiles. The enthalpy of limestone domain in the simulated pellets is used as an indicator of the extent of the SHS reaction. The activation energies, determined through isoconversional methods are observed to be 60–80% lower for SHS-based limestone calcination compared to conventional calcination. These reductions, which depend on the fuel content (higher fuel content leads to lower activation energy), underscores the ultrafast nature of the SHS process. Both SHS-based and conventional calcination routes are determined to follow the contracting geometry model, albeit with lower interface shrinkage dimension for the SHS pathway. A fundamental

understanding of the kinetics of SHS-based calcination allows for the process-optimization, enabling improved carbon- and energy-efficiency of the process.

1:45pm - Abstract #3488

Particle packing factor (P_{PF}): A quantitative parameter for designing sustainable UHPC

Bayezid Baten and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

Conventional UHPC mix-design strategies are mostly trial and error-based and lack quantitative metrics to optimize packing of the multiple binders involved. Here, we introduce the Particle Packing Factor (P_{PF}) - a novel mix-design metric derived from binder size distributions. On a range of 19 unique UHPC mixes, we find that the P_{PF} strongly correlates with numerous performance metrics. Specifically, the P_{PF} shows strong correlations ($R^2 = 0.7-0.9$) with rheological properties - increasing P_{PF} from 52 to 68 nearly doubles the HRWR efficiency (flow/HRWR) from 6.2 to 14.0 cm/%wt. A similar P_{PF} enhancement improved 3- and 28-day compressive strength by 34.9% (63 MPa to 85 MPa) and 39.0% (87 MPa to 121 MPa), respectively, while reducing open porosity from 8% to 2%. P_{PF} values strongly influence ($R^2 \sim 0.6-0.8$) sustainability indices which highlight the potential value of the PPF metric in designing and optimizing UHPC mixes for performance, cost, and sustainability.

2:00pm - Abstract #3493

Microalgae-produced CaCO_3 as a raw material for portland cement production

Danielle N. Beatty, Cansu Acarturk and Wil V. Srubar III, University of Colorado Boulder, Boulder, CO

Abstract Text:

In this work, we target clinker emissions reduction using carbon storing, photosynthetically produced CaCO_3 in place of quarried limestone to produce cement clinker. CaCO_3 produced by photosynthetic marine microalgae (a combination of coccolithophores *Emiliana huxleyi* and *Gephyrocapsa oceanica*) was investigated as a limestone source for clinker production. CaCO_3 was mixed with reagent grade SiO_2 , Al_2O_3 , and Fe_2O_3 , according to industrially utilized limestone saturation factor, silica ratio, alumina ratio, and Bogue calculations, and heated to synthesize clinker. Bulk cement clinker was synthesized at the lab scale and phase formation, hydration kinetics, and compressive strength were analysed. In situ high temperature X-ray diffraction was used to study in more detail the effects of microalgae-produced CaCO_3 with high surface area (12.22 m^2/g) on raw mineral reactivity during cement clinkering. Results show that the high purity and high surface area of microalgae-produced CaCO_3 leads to more efficient calcination at 50 °C lower temperature as compared to quarried limestone clinker. Microalgae-produced CaCO_3 led to similar clinker phase formation to that of quarried limestone. Results show that microalgae-produced CaCO_3 can be used as a carbon-storing limestone source for producing portland cements. The use of microalgae-produced CaCO_3 for clinker production represents up to a 60% reduction in cement production emissions (by closing the loop on calcination CO_2 release) and a paradigm shift for industrial minerals production.

2:15pm - Abstract #3548

Dissolution rate quantifications for cementitious magnesium silicate hydrate: Implications on concrete durability

Micah W Bob and Erika La Plante, UC Davis, Davis, CA

Abstract Text:

A substantial percentage of annual anthropogenic carbon dioxide emissions are the result of cement production. Since the beginning of the century, enhanced efforts have been made to research alternatives and additives that reduce the carbon dioxide output of these processes. The dissolution of the cementitious binder is pertinent to understanding the service life and durability of concrete in various applications. A proposed Ordinary Portland Cement (OPC) alternative, magnesium silicate hydrate (MSH), lacks essential data and analysis regarding the kinetics and mechanisms by which the material dissolves. Synthesized MSH of varying Mg to Si molar ratios, $[Mg]/[Si]$, ranging from 0.5 to 1.5 was dissolved in deionized water within a free floating chamber and the evolving solution was sampled over time and analyzed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). From these concentration data, release rates for each element ($[Mg]$ and $[Si]$) averaged over a period of 2 hours were determined to be 1.14×10^{-15} mol/cm²/s, with respect to Mg, and 6.13×10^{-16} mol/cm²/s, with respect to Si, an order of magnitude lower than that of calcium silicate hydrate (CSH), the binder in OPC, under equivalent environmental conditions. Questions regarding the incongruity of dissolution, including the initial favorable release of magnesium into solution, were further investigated. The results evaluated specific mechanisms of dissolution and solution saturation, such as the applicability of the affinity-based model, as well as the release of adsorbed magnesium ions from depolymerized silica groups. Our findings reveal the dependence of dissolution rate on the $[Mg]/[Si]$ ratio of MSH and the temporally evolving dissolution incongruity are caused by the evolving composition and pH of the residual reaction solution. Understanding dissolution kinetics of MSH in relation to CSH will verify its viability as an OPC alternative as the cement industry progresses towards sustainability.

2:30pm - Abstract #3641**Sustainable belite-ye'elimite-ferrite cement: Utilizing ladle metallurgy furnace steel slag for low-cost and carbon-efficient production**

Abdulkareem O Yusuf, Nannan Zhang, Gao Deng, Ugochukwu Ewuzie, Abiodun Saka, Hongyan Ma and Monday U. Okoronkwo, Missouri University of Science and Technology, Rolla, MO

Abstract Text:

Belite Ye'elimite Ferrite (BYF) cement has emerged as a promising sustainable alternative to Portland cement. However, one of the constraints in large-scale production is the high cost associated with bauxite, a critical source of alumina. To address this challenge, this study examines the potential utilization of ladle metallurgy furnace (LMF) steel slag as a sustainable and cost-effective to traditional materials in the raw mix design. Incorporating 82% LMF slag into the raw mix, this research promotes waste material valorization and align with circular economy principles. The synthesized BYF clinker featured 34.2% belite, 36.3% ye'elimite, 19.3% ferrite (mass basis), along with minor phases. To optimize hydration kinetics and strength development, various gypsum substitutions were tested, with performance benchmarked with commercial Portland cement (PC) and calcium sulfoaluminate (CSA) cement. Findings reveal that the LMF-based BYF clinker intermixed with 10 wt% gypsum exhibits compressive strength development similar to Type I/II PC, while the clinker intermixed with 20% gypsum exhibits strength development characteristics similar to a commercial CSA cement. The formulated BYF cement enables up to about 90% CO₂ emission reduction compared to PC and significantly reducing production costs by offering an almost complete replacement of bauxite and limestone with a nearly carbon-free and cost-free feedstock. Thermodynamic simulation was employed to complement and extend the analysis beyond the experimental duration, to provide more insight into microstructure evolution. This work projects the viability of LMF slag as a sustainable alternative raw mix in BYF cement production, aligning with global goals to decarbonize the cement industry and advance sustainability.

2:45pm - Abstract #3664

Optimization and performance assessment of geomimetic low-carbon cement

Chengyao Liang, Stewart Williams, Tiziana Vanorio, Matteo Cargnello, and Alberto Salleo, Stanford University, Palo Alto, CA

Abstract Text:

The cement industry is responsible for around 8% of global annual CO₂ emissions, underscoring the urgent need for more sustainable alternatives to ordinary Portland cement (OPC). Drawing inspiration from self-healing, fiber-reinforced rocks formed by Earth's natural processes, we propose a new generation of geomimetic construction materials. These materials offer performance on par with conventional OPC while providing significant sustainability advantages. Specifically, our material is derived from a blend of abundant calc-alkaline volcanic rocks, which naturally contain a calcium and alkali aluminosilicate composition—ideal for producing highly reactive hydraulic cementitious materials. With a lower calcination temperature and substantially higher calcination yield, this material significantly reduces CO₂ emissions during production. Its enhanced compatibility with chemical admixtures, such as polycarboxylate ether (PCE) superplasticizers, ensures superior fresh-state properties, improving workability during long-distance transportation. Additionally, self-propagating fibers embedded within the matrix offer excellent ductility, overcoming the dispersion challenges typically encountered with traditional reinforcing fibers. Overall, the material demonstrates mechanical strength and permeability comparable to OPC, making it a promising solution for durable, load-bearing infrastructure applications. This innovative approach presents a sustainable pathway forward, addressing both environmental impact and performance demands in the construction industry.

I: Cement Chemistry (Part 2 of 2)

Thursday, June 12, 2025, 3:15pm - 5:00pm

3:15pm - Abstract #3524

From days to minutes

Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

Traditional testing for cement-based materials has been historically time-intensive, ranging from days to weeks to sometimes even several months. Recent advances in instrumentation, sensors, and AI can accelerate some of these traditional tests. In this talk, I will outline our recent efforts to speed up testing from the timescale of days to minutes. Specifically, I will talk about three areas. The first area is SCM reactivity testing, where we've introduced a new UR2 test that can predict the 7d R3 test results in a matter of 5 minutes. The second area is that of durability testing, where we've introduced a droplet test that can predict sorptivity in a matter of few seconds. Finally, the third area is that of low-cost and rapid imaging for shape analysis of fine aggregates, where we can pinpoint the influence of particle shape parameters on mortar strength and workability. Overall, with these approaches, we aim to strive towards a future where rapid testing can lead to rapid deployment of new materials.

3:30pm - Abstract #3525

Interaction of calcium sulfoaluminate belite cements with alkanolamine admixtures: Insights from hydration and structural build-up at early ages

Tu-Nam Nguyen, Angus Wilkinson and Kimberly E. Kurtis, Georgia Institute of Technology, Atlanta, GA, and Elsa Qoku, Georgia Tech, Atlanta, GA, and Burak Uzal, Abdullah Gul University, Kayseri, Turkey

Abstract Text:

The effects of three alkanolamines (triisopropanolamine (TIPA), triethanolamine (TEA), and diisopropanolamine (DIPA)) at a dosage of 0.02% BWOC as admixtures on the hydration of calcium sulfoaluminate cement belite was examined. A hydration and microstructural study along with structure build up was carried out, utilizing isothermal calorimetry, TGA, in-situ XRD, and SEM for up to 72 hours of hydration along with amplitude-sweep rheology.

Calorimetry showed that TEA and DIPA retarded and reduced the main hydration peak compared to the control (~1.8 hours), while all the alkanolamines retarded and enhanced the shoulder (~3.5 hours) and secondary hydration peak (~37 hours). Ettringite was identified as the main crystalline hydration product, and AH_3 was identified by TGA. In-situ XRD suggests that TEA slows down ye'elimite dissolution. SEM images indicate differences in ettringite morphology. In the presence of TEA, ettringite was found to be hexagonal, but in the presence of DIPA elongated needles were observed. Samples containing alkanolamines demonstrated increased storage and loss moduli and extended linear viscoelastic ranges. The stress-moduli graphs revealed a "curving-out" behavior beyond yield for pastes containing TEA and DIPA, indicative of non-uniform structural breakdown. Ongoing research is examining the relationships between hydration, morphology and rheological behavior.

3:45pm - Abstract #3540

Linking composition and early-age mortar compressive strength of type IL cement

Zeyu Wang, Devon Golden, Collins Twum, and Kimberly E. Kurtis, Georgia Tech, Atlanta, GA, and Newell R Washburn, Carnegie Mellon University, Pittsburgh, PA

Abstract Text:

In recent years, many U.S. cement producers have transitioned from manufacturing ASTM C150 Type I/II portland cements to ASTM C595 Type IL portland limestone cements, which incorporate up to 15% by mass uncalcined limestone. Understanding and quantifying the variations in mineral composition introduced by different limestone contents and the impact on mechanical performance remains a critical research challenge. Here, 53 Type IL cement samples were sourced from 14 different manufacturers across the U.S., including cements from 19 states. Quantitative compositional analyses carried out, utilizing XRD, XRF and TGA. Via Rietveld refinement, 16 different phases were identified among the Type IL hydrated cements sampled. Calcite and dolomite, measured at 3.4–14.8% and 0–7.5% by mass respectively among these cements, are the main phases associated with uncalcined limestone. While often challenging to distinguish these two phases due to overlapping XRD peaks and/or their limited presence, by combining data from QXRD and TGA a strong correlation of 0.98 (adjusted $R^2=0.94$) was found in quantifying these phases, demonstrating consistency between the two methods. Additionally, physical properties, including specific gravity and particle size distribution, were measured. These compositional and physical characteristics are compared with performance measures, including mortar strength (ASTM C109).

The lab-measured 1-day strength range from 1430 to 3930 psi (9.9–27.1 MPa) with an average of 2030 psi (14.0 MPa), exhibiting a bimodal distribution. Based on the measured data, a series of interpretable predictive models were developed, establishing an initial relationship between mineral composition and early-age strength.

4:00pm - Abstract #3621

Cementitious properties of cast stone mixed with waste simulant of varying concentrations

Jonathan L. Lapeyre, Christopher Hossack, Mayra Diaz Acevedo, Matthew R. Asmussen and Gary L. Smith, Pacific North West National Laboratory, Richland, WA

Abstract Text:

Cast Stone, a ternary blend of blast furnace slag, fly ash and portland cement, is a candidate material for immobilizing low activity waste (LAW) originating from storage tanks located at the U.S. Department of Energy Hanford Site located in southeast Washington state. This study systematically investigated the change in rheological, thermodynamic, and physical properties of Cast Stone when mixed with simulated non-radioactive chemical LAW waste of varying concentrations generated from a 7.8 M Na stock simulant diluted over a range down to a 1.5 M Na solution. These alkaline simulants did not contain Land Disposal Restricted inorganic compounds such as Cr(VI) or organic compounds. The Cast Stone pastes made with the maximum and minimum concentration simulant exhibited opposite behavior in most instances such as set time and flowability, e.g., the Cast Stone mixed with 7.8 M Na simulant exhibited a set time of about 4 days compared to about 2 days for the 1.5 M Na simulant. But the maximum and minimum simulant mixtures exhibited reduced reactivity and degraded physical performance than the Cast Stone mixed with simulants of an intermediate concentration.

4:15pm - Abstract #3629

Understanding performance variability in Type IL cements

Yaman Garg and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

Type IL or Portland Limestone Cement (PLC) is positioned as a greener alternative to Ordinary Portland Cement by increasing the limestone fraction in cement up to 15%. However, reports point to significant fluctuations in the workability and performance of PLC concretes. Taking a selection of 12 Type IL cements from plants across the US, we find that early age strength (1-day), rheological consistency, and reactivity (24h cumulative heat of hydration) can vary by up to 85%, 250%, and 28%, respectively. Previously, Raman imaging has been utilized to measure the phase-specific particle size distributions (PSDs) of cements and successfully predict their reactivity through 72h cumulative heat. Here, we apply it

to a selection of these Type IL cements to investigate these significant differences in performance and workability. Combined with chemical composition, these PSDs can be a potential method to explain the observed performance of the analyzed cements through the construction of a Composition-PSD index.

4:30pm - Abstract #3648

Development of magnesia-based cement for the solidification of am/pu-bearing effluent and disposal at WIPP

William C Jolin, Savannah River National Laboratory, Aiken, SC

Abstract Text:

A novel magnesium oxysulfate-based cement was developed for the solidification of an oxidizing, possibly acidic, effluent bearing Pu and Am. Cementing is a current best practice for the solidification of aqueous transuranic waste due to a fixed, homogeneous, and monolithic waste form being created while providing adequate density for self-shielding/dose requirements. However, a traditional Portland-cement based mixture results in a high pH leachate from solidified waste form. High pH leachate stemming from the waste could lead to the formation of isosaccharinic acid (ISA), a known plutonium chelator, from the breakdown of collocated cellulosic waste. ISA production is not observed at the assumed brine pH of the Waste Isolation Pilot Plant (WIPP). Therefore, if the leachate for a prospective solidified waste form fell within the assumed pH range of the WIPP brine, it would not challenge the current performance assessment for the repository and would limit the concerns of ISA production. The pH of the WIPP brine assumed in the performance assessment for the repository is 9-10.5, due to buffering by MgO in the salt formation. Magnesium oxysulfate cement formulations were tested as a means to solidify a surrogate liquid effluent by using reactive MgO, anhydrous magnesium sulfate, and sand as a non-reactive heat sink. However, a full scale (55-gallon drum) test revealed that this mix results in excessive heat generation due to the exothermic magnesium oxysulfate formation and the material set prior to the preferred mixing period. The formulation was then reconfigured by substituting dead burnt magnesia for some of the reactive light burnt material to create a solidified form that generated less heat, but still provided the density required for self-shielding purposes. Overall, magnesium oxysulfate cement was concluded to be a promising technology to solidify Pu bearing aqueous waste.

4:45pm - Abstract #3662

Enhancing belite reactivity and mechanical performance: The role of chemical activators in hydration kinetics

Bryan K Aylas-Paredes, Missouri University of Science and Technology, Rolla, MO

Abstract Text:

The effect of chemical activators on the hydration mechanism of β -dicalcium silicate (β -C₂S) was investigated, focusing on dissolution-precipitation kinetics and mechanical performance under varying activator concentrations. Hydration was characterized using isothermal calorimetry, thermogravimetric analysis (TGA), and Fourier-transform infrared spectroscopy (FTIR). Results indicate that activators are more effective when dissolved in solution rather than added as a dry powder. Sulfate ions accelerate nucleation and growth by increasing the supersaturation of calcium and silicate species, reducing the induction period to less than 20 hours. In contrast, hydroxide ions retard hydration by promoting early portlandite (CH) precipitation, which depletes free calcium needed for sustained calcium silicate hydrate (C-S-H) formation. Compressive strength tests reveal that sulfate and carbonate activators enhance the mechanical performance of β -C₂S by up to 15%, further demonstrating their role in improving early reactivity and structural development. Additionally, the incorporation of chemical activators increases the overall degree of hydration by up to 30%. These findings have direct implications for low-clinker cements, alternative binders, and performance optimization in sulfate-rich environments, contributing to the development of more sustainable and high-performance cementitious materials.

J: Sustainability (Part 2 of 3)

Thursday, June 12, 2025, 3:15pm - 5:00pm

3:15pm - Abstract #3490

Carbon-negative lightweight aggregates: Biochar-based solutions for sustainable concrete

Katherine Ann King, Tung Hoang, Lori Tunstall and Ahmadreza Hedayat, Colorado School of Mines, Golden, CO

Abstract Text:

Lightweight concrete (LWC) is critical for structural applications such as multi-story buildings, bridges, and roof decks. However, conventional lightweight aggregates (LWAs) are often carbon-intensive and costly. This study explores the feasibility of producing a synthetic, carbon-negative LWA created through cold-bonding granulation of biochar. In this pelletization process, biochar, cement, and water are combined in a pan granulator to form LWAs. The study examines the effects of LWA curing conditions on LWA properties and their impact on LWC strength. The LWAs were produced using 33% cement by mass, an average biochar initial moisture content of 22.5% (dry basis), and a curing time of 7, 14, and 28 days. Concrete specimens incorporating this LWA as a 100% coarse aggregate replacement met ASTM low-density requirements for structural LWC by achieving an average density of 1580 kg/m³. Additionally, the mix design had an average negative embodied carbon. These findings demonstrate the potential for biochar-based LWAs to serve as a sustainable alternative to conventional LWAs, offering both structural viability and carbon-negative benefits for lightweight concrete applications.

3:30pm - Abstract #3521

Evaluating biochar as an internal curing agent in cementitious systems

Julia Hylton, Lori Tunstall, and Fatemeh Hamidi, Colorado School of Mines, Golden, CO

Abstract Text:

As the concrete industry pursues scalable solutions to reduce the embodied carbon, few alternatives achieve both emissions reductions while maintaining comparable performance. The use of biochar as a partial cement replacement shows string potential to offset carbon emissions while enhancing mechanical properties. A key characteristic of biochar is its high sorption capacity, which negatively impacts fresh mix workability but may facilitate internal curing by releasing sorbed water. This study quantifies the sorption capacity of three distinct milled biochars for the first time and evaluates their desorption behavior to assess internal curing potential. Additionally, dry and fully saturated biochars were incorporated into mortar mixes to examine the effects of water availability on rheology, strength development, and hydration. Results indicate that only specific biochars effectively function as internal curing agents, highlighting the importance of oxygenated surface chemistry for optimizes performance.

3:45pm - Abstract #3569

Multiscale investigation of clay-biopolymer interactions for sustainable earth-based concrete

Rebecca A. Mikofsky, Samuel J. Armistead, and Wil V. Srubar III, University of Colorado Boulder, Boulder, CO and Yierfan Maierdan and Shiho Kawashima, Columbia University, New York City, NY

Abstract Text:

Earthen concrete offers a promising alternative to the high environmental impacts of conventional concrete materials. Earth is a natural material comprised mainly of subsoil, which is often produced as a construction waste product and provides excellent thermal properties. However, traditional earthen materials are often low-strength and have durability issues. This study investigates physicochemical interactions between five polysaccharides (guar gum, locust bean gum, methylcellulose, sodium alginate,

xanthan gum) and two common clays (bentonite and kaolinite), linking these interactions to fresh- and hardened-state properties. Through utilizing binding characterization (Fourier-transform infrared spectroscopy, thermogravimetric analysis, zeta potential), it was found that non-ionic galactomannans (guar gum and locust bean gum) bind to both clays, non-ionic methylcellulose binds primarily to bentonite, and anionic biopolymers (sodium alginate and xanthan gum) exhibit no binding with clays. It was also determined that biopolymer-clay binding affinity directly correlates with static yield stress: binding causing stiffening, and non-binding causing plasticizing. While all biopolymers increased unconfined compressive strength, the highest strengths (13.7 ± 1.3 MPa in bentonite, 8.0 ± 0.5 MPa in kaolinite) were achieved using sodium alginate, a low molecular weight anionic biopolymer. These fundamental insights on clay-biopolymer interactions and their effects on macro-scale properties are critical for developing modern, sustainable, high-performance earthen concrete.

4:00pm - Abstract #3651

Closing the concrete loop: Effect of SCMs on material circularity

Aniruddha Baral, University of Leeds, Leeds, United Kingdom, and The University of Texas at Austin, Austin, TX, and Theodore Hanein, University of Leeds, Leeds, United Kingdom

Abstract Text:

Infrastructure in developed countries is aging, and rehabilitating or reconstructing these facilities would generate large amounts of concrete waste. Furthermore, vast amounts of concrete waste are generated through conflict and disaster. A closed-loop recycling of concrete waste would reduce the cost, resource intensity, and carbon dioxide emissions of concrete production. Recent innovations in waste concrete-crushing technologies enable the separation of waste concrete into three parts: hardened cement paste (HCP) with minimal sand content, fine aggregate (or sand), and coarse aggregates. Fine and coarse aggregates can be reused for manufacturing concrete, but the effective recycling of the HCP to generate a hydraulic binder remains challenging. Specifically, the usage of supplementary cementitious materials alters the oxide composition of the HCP considerably from that of traditional Portland cement, requiring a large amount of virgin materials if HCP is to be returned into a clinker. In this presentation, we have considered waste concrete with different types of cement, SCM types, and amounts to investigate their recyclability. We found that large amounts of SCM-containing HCPs can be more efficiently recycled as belitic calcium sulfoaluminate-based cement (BCSA). In contrast, HCPs with minimal SCM content or CEM I cement can be recycled as Portland cement. Finally, the amount of sand content in HCPs reduces their recyclability, and the reduction is higher in BCSA compared to PC.

4:15pm - Abstract #3671

Rheology of high-performance 3D printed cementitious materials incorporating recycled concrete

Kathryn Eileen Sheehan Jones, University of California Irvine, Irvine, CA

Abstract Text:

Introducing recycled concrete into 3D printed cementitious materials can reduce environmental impacts while utilizing locally sourced recycled ingredients. However, printable concrete materials are highly sensitive to changes in mix design, which can adversely affect their rheology, printability, and mechanical strength. This study evaluates the effects of recycled concrete as fine aggregates on the early-age rheology and printability of cementitious materials, using a 3D printable high-strength cementitious material as a baseline. Fine aggregates were recycled from three different concrete sources, mortar and 3D printed concrete with controlled water-to-cement ratios, and concrete from commercial demolition sites. These aggregates were characterized and used to replace sand at different percentages, with controlled particle size distribution and water absorption. The changes in early age rheology and thixotropic behavior were studied over a one-hour printing window. The results show that at 100% volumetric substitution, the yield stress increased substantially when the recycled aggregates were made from mortar or concrete from demolition site, whereas it decreased when the recycled aggregates were made from the high-strength cementitious material, pushing the resulting cementitious material either

above or below the optimal printability range. This study generates insights on how recycled concrete can be effectively integrated into 3D-printed material systems without significantly compromising its rheology and mechanical strength.

4:30pm - Abstract #3381

Sustainable and affordable 3D printable concrete using quarry by-products

Anasuya Kamakshi Tippabhotla, Aidyn Tugelbayev, Bao Chau, Anderw P. McCoy and Alexander S. Brand, Virginia Tech, Blacksburg, VA

Abstract Text:

3D concrete printing (3DCP) is rapidly growing due to its wide range of advantages over conventional cast concrete. However, one major concern is that 3DCP mixes typically have high cement contents and have a high carbon footprint as a result. Quarry by-products (QB) are a significant waste material available in the US, with estimated productions close to about 175 Mt/yr. Using QB as a partial replacement to cement would not only reduce the carbon footprint but also show a viable usage for the otherwise waste material. In this study, QB pond fines resulting from washing crushed stone was used as a partial replacement of cement and QB screenings resulting from gradation limits was used as a full replacement of the fine aggregate. Pond fines have a dual purpose in this study: replacing cement partially and also as a rheology modifier to aid with shape retention and thixotropy of 3D printable concrete. The suitability of this concrete for the purpose of 3D concrete printing is determined based on the strength (compression and tension), material characterization (calorimetry and XRD), rheology (viscosity, yield stress, and thixotropy) and print properties (extrudability, shape retention, and buildability). Prototyping of products is conducted using a Tvasta SIRA RC-20 mobile robotic arm 3D concrete printer.

4:45pm - Abstract #3656

Eco-friendly sand-concrete composite: Integrating recycled PVC for improved thermal and environmental properties

Aboulkacem Moutie Hamed, Zeghichi Leila, Hocine Siad and Karima Gadri, University of Biskra, Biskra, Algeria and Mohamed Lachemi, Toronto Metropolitan University, Toronto, ON

Abstract Text:

The growing demand for sustainable and lightweight construction materials has led to increased interest in incorporating recycled plastic waste into concrete composites. This study investigates the influence of recycled PVC Pipe waste as a partial sand replacement in sand concrete on its physical, mechanical, thermal, and environmental properties. The results indicate that increasing PVC content from 0% to 30% leads to a notable reduction in dry density due to the lower density of plastic aggregates. However, compressive strength decreases non-linearly, with a 40.4% reduction at 30% PVC substitution, attributed to weak interfacial bonding. Thermal conductivity measurements show a significant decline, with a maximum reduction of approximately 51%, improving the insulating properties of the composite. Additionally, water absorption increases by 27.3% due to the increased porosity caused by plastic inclusion. A life cycle assessment (LCA) reveals that incorporating PVC reduces CO₂ emissions by up to 5.63%, though a slight increase in energy consumption is observed due to plastic processing. These findings confirm the potential of PVC-modified sand concrete as an eco-friendly alternative with enhanced thermal insulation, albeit with mechanical strength trade-offs that must be addressed for structural applications.

K: Sustainability (Part 3 of 3)

Friday, June 13, 2025, 10:00am – 11:30am

10:00am - Abstract #3435

Optimization of carbonated supplementary cementitious materials production

Jonathan J Smith and Juan Pablo Gevaudan, Pennsylvania State University, State College, PA

Abstract Text:

Multiple methods of storing CO₂ in portland cement waste, fly ash, slags, and mafic rocks have been explored in literature ranging from diffusion based carbonation in environmental chambers, high pressure carbonation in autoclaves, and monoethanolamine-based accelerated carbonation. However, these methods result in adverse relationships when these materials are to be used as cement replacements, namely between rheological performance and a higher carbonation degree causing workability challenges, and extensive reaction times. This presentation will report on recent investigations of a novel mechano-carbonation process that exfoliates passivation layers formed by silica gels during carbonation decreasing reaction times from several hours to minutes. Currently, while the potential for the symbiotic use of milling, acidification, and enzymatic processing conditions can greatly reduce specific energy requirements of mechano-carbonation, these processes have seldom been explored. With laboratory scale experiments and simulated commercial scale modeling using Discrete Element Method (DEM) modeling, our results demonstrate the carbonation potential and energy requirements for a broad range of potential applications including acid mechano-carbonation treatment of olivine sand, acid milling of smectite clays, and mechano-carbonation of portland cement pastes. Our findings show significant advancements in the fundamental reaction mechanisms underpinning carbonation of cement replacements. These benefits are maximal with acidic milling treatments rapidly decomposing and forcing Ca²⁺ ions into solution subsequently resulting in rapid CaCO₃ formation aided by the low-pH dissolution of carbonic acid from carbonic anhydrase (CA-IX). These novel processes additionally alter the water demand and workability properties of the resulting SCMs, potentially offering pathways to decouple workability and carbonation degree of resulting CO₂ sequestering cement replacements.

10:15am - Abstract #3455

Stability of two-phase flow with interfacial flux in CO₂ mineralization: Theory for complex system evolution

Roi Roded and Laura E. Dalton, Duke University, Durham, NC

Abstract Text:

The primary objective of Carbon Capture and Storage (CCS) applications in porous media is to achieve a stable and planar CO₂ displacement front, thereby suppressing viscous fingering. Particularly, a stable front can ensure uniform and exhaustive carbonation throughout a reactive medium. Drawing inspiration from experimental observations of CO₂ flooding into cores of portland cement-based materials, we examine the stability of such systems. Focusing on the early injection time allows us to reduce the complex problem, typically involving thermo-hydro-mechanical-chemical interactions, into a two-phase flow scenario of immiscible displacement with an interfacial flux (from the invading CO₂ phase into the resident water solution). This simplification is then justified a posteriori.

The formulated equations with the interfacial flux term are used to investigate the development of a saturation profile and define a base-state solution for linear stability analysis. Assuming negligible capillary forces and a step-profile allows us to derive a closed-form stability criterion. Findings show that the interfacial flux can either suppress or promote perturbations depending on the saturation profiles, typically leading to stability enhancement. Implications are then briefly drawn. Finally, this research demonstrates the important role of theory in simplifying complex multi-physical and scale processes and inferring the ultimate state of subsurface systems.

10:30am - Abstract #3421

Inter-grinding and carbonated curing of basalt-based alkali-activated materials: Toward sustainable solutions on earth and beyond

Sophia Liron Bergen and Claire E. White, Princeton University, Princeton, NJ

Abstract Text:

This research talk will highlight ongoing work investigating the effects of grinding and carbonated curing conditions to enhance the viability of using lunar regolith and basalt as aluminosilicate precursors for alkali-activated materials (AAMs). Lunar Mare Simulant (LMS-1), designed to replicate lunar regolith's physical and chemical properties, is composed of terrestrial rocks and minerals including basalt—Earth's most abundant igneous rock. Both materials are highly crystalline and relatively inert, posing challenges for alkaline activation. Ball milling is well-known to reduce particle size and can induce some degree of structural disorder and surface amorphization that enhances reactivity. When milled with a solid alkali source, this inter-grinding approach enables the production of one-part AAMs, offering a "just add water" approach. Additionally, CO₂-rich fluids have been shown to enhance the dissolution of calcium-, magnesium-, and sodium-bearing silicate minerals in basalt, accelerating the formation of stable carbonate phases. Here, preliminary experiments combining inter-grinding, elevated temperatures, and carbonated curing conditions have demonstrated improved mechanical properties in LMS-based one- and two-part AAMs. Additionally, pure-phase analysis of individual composite minerals, such as anorthosite and bronzite, provides deeper insight into their reactivity, dissolution behavior, and transformation mechanisms in alkali solutions and carbon-rich environments. Beyond its implications for in-situ resource utilization in space, this research highlights basalt's potential as a sustainable precursor for AAMs on Earth. By leveraging abundant and naturally CO₂-reactive materials, basalt-based AAMs could reduce reliance on traditional Portland cement. This work highlights the interconnected benefits of planetary and terrestrial materials science, bridging space exploration with sustainable development on Earth.

10:45am - Abstract #3507

CO₂ mineralization mechanism of chlorellestadite

Vikram Kumar, Mohamed Abdelrahman, Hyeonseok Jee, and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

Cement manufacturing via alternative fuels such as waste plastics and chloride-rich raw materials increases the amount of Cl introduced in the kiln, resulting in the formation of chlorellestadite (Ca₁₀(SiO₄)₃(SO₄)₃Cl₂) – a water-insoluble Cl-containing phase. Recent studies indicate that chlorellestadite reacts with CO₂ and develops strength, demonstrating its potential as a carbonatable binder. However, the precise carbonation reaction mechanism of chlorellestadite is not well understood. To address this gap, we examined the reactivity of high-purity synthetic chlorellestadite with CO₂ and propose a new reaction mechanism. Our results suggest that chlorellestadite reacts with CO₂ via three parallel reactions to form CaCO₃, gypsum (CaSO₄·2H₂O), amorphous SiO₂, calcium chlorosilicate (Ca₃(SiO₄)Cl₂), and sinjarite (CaCl₂·2H₂O) with a potential to sequester 29.7% CO₂. Given this CO₂ uptake potential, we find that cement blended with chlorellestadite can be subject to simultaneous hydration and carbonation, forming binders with enhanced strength and a reduced CO₂ footprint.

11:00am - Abstract #3528

Regulating the carbonation of hardened cement paste for enhanced carbon sequestration and pozzolanic reactivity

Xi Chen, Xiaodong Wang, Monica Amaral, Maysam Bahmani, Abdulmalik Alawode and Jialai Wang, The University of Alabama, Tuscaloosa, AL

Abstract Text:

This study presents an innovative CO₂ mineralization strategy that transforms hydrated cement paste (HCP) into a carbon-negative, carbonate-rich supplementary cementitious material (SCM) while permanently storing CO₂. Extensive research has demonstrated that CO₂ mineralization of HCP not only sequesters carbon but also enhances its pozzolanic reactivity. However, maximizing the carbon benefits of this technology requires improving both carbonation efficiency and energy consumption. To address this, we propose to regulate the carbonation process of the HCP using a biomolecule, tannic acid (TA), as a small dose admixture. TA forms calcium complexes, facilitating HCP dissolution and seeding carbonation, while also significantly modifying the polymorph and morphology of the carbonation products. This approach enables complete carbonation of HCP within a short timeframe—something unachievable through conventional carbonation processes. Cement mortar incorporating the carbonated HCP exhibits 60% higher compressive strength than mortar with untreated HCP, confirming its superior pozzolanic reactivity. When scaled, this technology could permanently sequester over 10 million tons of CO₂ annually in carbon-negative SCMs, while preventing an additional 35 million tons of CO₂ emissions through reduced clinker demand.

11:15am - Abstract #3603

CO₂ uptake in basaltic fines

Wasiu Olaniyi Alimi, Sofiane Amroun and Prannoy Suraneni, University of Miami, Coral Gables, FL

Abstract Text:

The CO₂ mineralization potential of basalt has been widely reported in the literature, yet the underlying mechanisms and chemistry of the process remain poorly understood. Given the abundance of basalt, understanding the chemistry of carbon capture and its effect on the properties of basalt, especially as cementitious material, is essential. This study investigates raw /treated basaltic fines and olivine sourced from different locations exposed to a highly concentrated CO₂ environment under moderate exposure conditions. The CO₂ uptake, carbonating mineral, and changes in reactivity after CO₂ exposure were evaluated. Contrary to literature reports, Initial findings reveal no CO₂ capture and no significant change in basalt properties following CO₂ exposure.

L: Supplementary Cementitious Materials (Part 2 of 2)

Friday, June 13, 2025, 10:00am – 11:30am

10:00am - Abstract #3405

Mechanochemical activation of supplementary cementitious materials

Sofiane Amroun and Prannoy Suraneni, University of Miami, Coral Gables, FL

Abstract Text:

Cement is often partially replaced with supplementary cementitious materials (SCMs) to reduce the CO₂ emissions associated with its production. However, shortfalls of commonly-used SCMs are being increasingly reported. Alternatives exist, however, many of these need to be processed significantly before being used. Mechanochemical activation (MCA) is one way in which inert materials can be transformed into SCMs. In MCA, crystalline materials are transformed into amorphous ones through high-speed grinding. In this work, we focus on the effect of MCA on different materials. Basaltic fines (BF) showed increased heat release from the Modified R³ test with increasing grinding time and ball-to-powder ratio. Partial amorphization of the powders was evident from X-ray diffraction (XRD). Scanning electron microscopy (SEM) revealed the formation of rounded particles, aggregates, and agglomerates. Reactivity strongly correlated to the amorphous content but not to the increased BET specific surface area. MCA was also performed on 12 different materials. The increase in reactivity after MCA was found to have a logarithmic correlation with the initial reactivity of the materials. The mechanical properties of cement paste and mortar specimens containing mechanochemically activated SCMs were studied. Mechanochemically activated SCMs showed higher heat release, calcium hydroxide consumption, strength, and bulk resistivity in the tested pastes and mortars, compared to the raw materials.

10:15am - Abstract #3429

From filler to framework: Mechanisms and performance improvement in cement-struvite system

Ugochukwu Ewuzie and Monday U. Okoronkwo, Missouri University of Science and Technology, Rolla, MO

Abstract Text:

The development of sustainable and high-performance cementitious materials has driven the need for innovative alternatives that optimize rheological behavior, mechanical properties, and microstructural integrity. This pioneering study reports the mechanisms of rheological and mechanical performance of Portland cement-struvite (PCS) composites produced by partially replacing OPC with 3–20 wt% (PCS3–PCS20) struvite. The influence of struvite (ST) on OPC's hydration kinetics, pore structure evolution, rheology, phase reconstruction, and mechanical performance was comprehensively evaluated using isothermal calorimetry, 3D micro-computed tomography (μ XCT), time-dependent rheometry, X-ray diffraction (XRD), and Fourier-transform infrared spectroscopy (FTIR). The 3D μ XCT revealed a 41.7% reduction in resolvable porosity after 28 days for PCS10 compared to the control. Rheological investigations revealed 351% and 672% higher static yield stress for PCS15 and PCS20, respectively, compared to the control within 30 minutes, while their reduced plastic viscosity ensured improved workability and extended placement limits without viscosity modification additives. Mechanical strength was significantly enhanced compared to the control, with compressive (0.4%) and flexural (40.7%) strength gains for PCS20 after 28 days of curing. The mechanisms governing the PCS system's enhanced performance are driven by increased Ca²⁺ adsorption on ST negatively charged surfaces, which induces early flocculation, retards the hydration process, optimizes hydration product nucleation, strengthens interfacial adhesion, and facilitates microstructural densification. Furthermore, following the US EPA's greenhouse gas protocol, PCS20 achieves a $\geq 19.76\%$ reduction in absolute CO₂ emissions, aligning with sustainability goals while maintaining high structural integrity. This study demonstrates that

ST in the PCS system acts beyond a mere filler, actively improving cement hydration kinetics and structural performance without forming non-native OPC hydration products that impact durability.

10:30am - Abstract #3434

Long-term experimental investigation of high-temperature hydration phases forming in cementitious systems with added aluminosilicates

Lyn Zemberekci and **Sriramya D Nair**, Cornell University, Ithaca, NY

Abstract Text:

Subsurface infrastructure exposes cement to high-pressure and high-temperature (HPHT) conditions during hydration. This exposure influences phase morphology and crystallinity of hydration products and may enable the formation of metastable phases. When aluminosilicate sources are employed, our previous analysis of such phases at an early age revealed that C-A-S-H accounts for up to ~70% of the microstructure. Amorphous Al-rich C-A-S-H dominates the outer product, and a mixture of crystalline mineral-like C-A-S-H phases co-exist with a lower atomic percent of Al than the amorphous type. However, early-age hydration products may transform with time in such extreme environments at HPHT. Transformation to weaker phases is detrimental to the long-term stability of cementitious systems in subsurface environments. In addition, current knowledge on the transformation phenomenon of mineral-like phases and their thermodynamic stability relies on model C-S-H and C-A-S-H phases that are often synthesized by adjusting starting Ca/Si and Al/Si ratios, or by hydration of single cement phases, such as C3S. Therefore, there is a necessity to experimentally investigate phase transformation kinetics in complex cementitious systems and when aluminosilicates are added with varying starting oxide compositions. In this work, we aim to analyze the microstructural evolution of cement slurries that were hydrated under HPHT conditions for a month and then transferred to hydrothermal autoclaves for long-term hydration for a total time of 3 months, 6 months, and a year. The analysis is done using powder X-ray Diffraction and Scanning Electron Microscopy with Energy Dispersive Spectroscopy.

10:45am - Abstract #3451

Optimization of hydrothermal synthesis of kaolinite for the production of pure metakaolin

Paolo Camesasca, D-BAUG - IfB, ETH Zürich, Zürich, Switzerland, **Franco Zunino**, University of California, Berkeley, Berkeley, CA and **Andrea Testino**, PSI Center for Energy and Environmental Sciences, Paul Scherrer Institute, Villigen, Switzerland

Abstract Text:

The significant global warming potential of concrete and Portland cement production has led to increasing attention on supplementary cementitious materials (SCMs) as a viable solution for reducing the CO₂-intensive clinker component. Among these, calcined clays (CCs) and limestone (LS) have emerged as the most promising SCMs due to their abundant availability. The metakaolin (MK) present in CCs plays a key role in the success of low-carbon cements, such as LC3, where its reactivity, in synergy with calcium carbonate from LS, significantly contributes to strength and performance development in cementitious systems.

To enable precise and reproducible studies on the reactivity and kinetics of MK in various cementitious environments, pure synthetic MK is produced by calcining hydrothermally synthesized kaolinite. The goal of this project is to synthesize a material that mirrors the characteristics and properties of industrially available MK derived from natural kaolinite. Based on existing literature, the synthesis process was optimized to maximize purity and yield, while minimizing reactant loss. Thermodynamic simulations were employed to identify optimal conditions for MK production, and the predicted parameters were validated through lab-scale synthesis experiments. The resulting material was extensively characterized using multiple techniques: TGA for purity analysis, powder XRD for phase composition and crystallinity, SEM for morphology and microstructure, NAD-BET for specific surface area, LS for particle size distribution, and micro-scale calorimetry and R3 test for pozzolanic reactivity. An additional effort was made to enhance

the properties of the synthetic material with regard to NMR analysis. The material's long relaxation time, related to its high purity, was improved by introducing iron atoms as paramagnetic centers, thereby facilitating more effective analysis.

This work presents a detailed approach to producing a high-purity synthetic MK, providing valuable insights into the material's properties and performance in cementitious systems, and contributing to the development of more sustainable cement technologies.

11:00am - Abstract #3467

Cement hydration kinetics and mechanical property development in blended cement systems with supercritical CO₂-treated off-spec coal combustion residue.

Sarah Hlaihel, Santiago El Awad, Sondos Hlayhel, Ahmed Senouci and Konrad J Krakowiak Dr., University of Houston, Houston, TX

Abstract Text:

This talk will present the results of an extensive experimental campaign focused on cement hydration kinetics and mechanical property development in blended cement systems with supercritical CO₂-treated off-spec low-lime coal combustion residue (CCR). This study addresses the dual challenge of CO₂ sequestration and industrial waste valorization. The experimental campaign includes quantifying the extent of CO₂ carbonation by monitoring weight change before and after carbonation, pressure drop during carbonation, and X-ray diffraction (XRD) and thermogravimetric analysis (TGA). Moreover, the hydration kinetics in supercritical CO₂-treated CCR-modified cement pastes is evaluated using isothermal calorimetry. Additionally, the mechanical performance of carbonated CCR is assessed through micro indentation and compressive strength testing. The results demonstrate that CO₂-mineralized CCR can positively influence early-age hydration kinetics, and the availability, origin, and nature of sulfur-containing anions present in the original CCR strongly influence the extent of this impact. The presented approach offers a viable pathway for integrating carbon capture and utilization (CCU) strategies into concrete technology.

11:15am - Abstract #3479

UR²: An ultra-rapid reactivity test for supplementary cementitious materials

Yujia Min, Hossein Kabir, Chirayu Kothari, Muhammad Farjad Iqbal and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

The 28d strength activity index has been widely used for assessing the reactivity of supplementary cementitious materials (SCMs). Even though the R³ test reduces this duration to 7d, faster testing is still needed for quality control and assurance of emerging SCMs. This study investigated 100+ SCMs including calcined clays, fly ashes, and natural pozzolans, and developed a novel reactivity test called UR². The concentrations of ions released during the 5-15 min dissolution of SCMs were combined into dissolution indexes which strongly correlated to the 7d cumulative heat release during R³ tests and the 28d mortar compressive strength (R² >0.9). In addition, a colorimetry and camera-based method was developed to enable low-cost analysis of ion concentrations. This UR² method can enable real-time and low-cost reactivity assessments on the production line, allows for instantaneous adjustments of production conditions for sustainable SCMs including calcined clays, and facilitates their deployment at commercial scale.

Poster Session

Wednesday, June 11, 2025, 5:00pm – 7:00pm

Abstract #3375

Fresh properties of biochar-amended concrete

Fatemeh Hamidi, Colorado School of Mines, Golden, CO and **Lori Tunstall**, Colorado School of Mines, Golden, CO

Abstract Text:

Due to the lack of fundamental research on the rheology of biochar-amended concrete, this study investigates the optimization of flow properties in biochar-amended concrete to improve workability, mechanical performance, and durability. Biochar, known for its high specific surface area (SSA) and water adsorption capacity, poses challenges in concrete mixtures, including reduced flowability and agglomeration. In this study, the compatibility of three commercially available polycarboxylate-based chemical admixtures was assessed with biochar-amended concrete, using moderate (~50%) to high (~92%) carbon content biochars. Scaled-down experiments on biochar mortar were conducted to determine the saturation dosages of the chemical admixtures, while Zeta potential analysis confirmed the most compatible chemical admixtures for biochar-concrete systems. Subsequently, biochar-amended concrete mixes were prepared using the saturation dosages obtained for the biochar mortar. The use of optimized chemical admixture dosages for the biochar concrete effectively enhanced dispersion and maintained fluidity at biochar contents of 5–15% by cement weight, achieving slump values of 15–17 cm. The optimized biochar-concrete exhibited low porosity (<8%), compressive strengths exceeding 28 MPa, and dry densities comparable to control mixes. This study provides a framework for integrating higher dosages of biochar into concrete, emphasizing the importance of balancing biochar's physiochemical properties to achieve desired rheological performance while minimizing trial-and-error in mix design. The results highlight biochar's ability to transform concrete into a sustainable material with robust mechanical properties, advancing sustainable construction practices.

Abstract #3381

Sustainable and affordable 3D printable concrete using quarry by-products

Anasuya Kamakshi Tippabhotla, Aidyn Tugelbayev, Bao Chau, Anderw P. McCoy and Alexander S. Brand, Virginia Tech, Blacksburg, VA

Abstract Text:

3D concrete printing (3DCP) is rapidly growing due to its wide range of advantages over conventional cast concrete. However, one major concern is that 3DCP mixes typically have high cement contents and have a high carbon footprint as a result. Quarry by-products (QB) are a significant waste material available in the US, with estimated productions close to about 175 Mt/yr. Using QB as a partial replacement to cement would not only reduce the carbon footprint but also show a viable usage for the otherwise waste material. In this study, QB pond fines resulting from washing crushed stone was used as a partial replacement of cement and QB screenings resulting from gradation limits was used as a full replacement of the fine aggregate. Pond fines have a dual purpose in this study: replacing cement partially and also as a rheology modifier to aid with shape retention and thixotropy of 3D printable concrete. The suitability of this concrete for the purpose of 3D concrete printing is determined based on the strength (compression and tension), material characterization (calorimetry and XRD), rheology (viscosity, yield stress, and thixotropy) and print properties (extrudability, shape retention, and buildability). Prototyping of products is conducted using a Tvasta SIRA RC-20 mobile robotic arm 3D concrete printer.

Abstract #3382

Microstructural evolution and phase development in ultra-low clinker cement: A thermodynamic and experimental study

Abiodun Saka and Monday U. Okoronkwo, Missouri University of Science and Technology, Rolla, MO

Abstract Text:

The development of low-carbon cementitious binders is crucial for reducing CO₂ emissions while maintaining structural performance. This study evaluates the hydration kinetics, phase evolution, and mechanical properties of three binder systems with over 80% clinker replacement through supplementary cementitious materials. The formulated binders include Mix A (substituted with 30% slag + 51.62% limestone), Mix B (substituted with 10% fly ash + 20% slag + 51.62% limestone), and Mix C (substituted with 10% fly ash + 30% slag + 41.62% limestone). Compressive strength measurements of pastes at 1, 7, and 28 days revealed superior performance of Mix C, followed by Mix A and Mix B, achieving strengths ranging from 25 - 33 MPa at 28 days, comparable to commercial low-carbon cements (LC3). Thermodynamic simulations over 1200 days using the Parrot model demonstrated an inverse relationship between strength development and capillary porosity ($C < A < B$), indicating that the highest-strength binder exhibits the lowest porosity through enhanced microstructural densification. The evolution of key hydration products including C-S-H, ettringite, hydrogarnet, and monocarbonate, followed the pattern $C > A > B$, aligning with both strength results and XRD analysis at 28 days. The XRD findings confirmed that the estimated amorphous phase content followed the same sequence, validating the simulation predictions.

Abstract #3412

X-ray reflectivity as a tool to study dissolution kinetics of calcium silicates

Aidyn Tugelbayev and Alexander S. Brand, Virginia Tech, Blacksburg, VA

Abstract Text:

X-ray Reflectivity (XRR) is a surface-sensitive technique used to analyze thin films, surfaces, and interfaces at the nanoscale. While widely applied in materials science and geochemistry, its potential in cement chemistry remains largely unexplored. This work investigates XRR as a tool for characterizing the dissolution kinetics of calcium silicate phases by analyzing both thin films and polished solid surfaces. By tracking changes in surface layer thickness and density before and after exposure to water, XRR can identify non-classical dissolution pathways such as coupled interfacial dissolution-precipitation (CIDR) in calcium silicates. Preliminary data suggest density changes in the surface layer of polished calcium silicate samples, indicating the potential formation of an altered layer during dissolution. Further XRR analysis of calcium silicate thin films will directly correlate changes in total external reflection and Kiessig fringe periodicity with nanoscale alterations in density and film thickness upon dissolution, respectively. These insights will further refine kinetic models of cement phase dissolution, contributing to the development of more durable and sustainable cements.

Abstract #3438

LC3-like systems made with u.s blends of portland limestone cement and calcined clays

Paola Huynh, Maria Juenger, and Thien Tran, University of Texas at Austin, Austin, TX, Kejin Wang, Iowa State University, Ames, IA, and Kimberly E. Kurtis and Daniel J Benkeser, Georgia Institute of Technology, Atlanta, GA

Abstract Text:

Concrete production today increasingly relies on supplementary cementitious materials (SCMs) or natural pozzolans to reduce clinker, a key contributor to carbon emissions. However, the availability of materials such as slag and fly ash is decreasing. Calcined clays derived from kaolinite have emerged as a

promising alternative due to their abundance and favorable physicochemical properties. Calcined clays show prominent potential in limestone calcined clay cements (LC³). LC³ cements are composed of 30% calcined clay, 15% limestone, 5% gypsum, and 50% clinker, offering a viable solution for reducing clinker usage while maintaining performance standards.

This study evaluated the feasibility of LC³-like systems using materials commercially available in the US. Three calcined clays were each paired with their respective local or nearby Type IL cements and additional powdered limestone to create mortar mixtures. One mixture contained an IP cement, which included a calcined shale. This research aimed to develop LC³-like systems that achieved target flowability, passed strength requirements, and reduced environmental impact.

Cement-clay blends were designed to have the lowest percentage of clinker, not exceed the manufacturer's allowable dosage of superplasticizer, and still meet ASTM C595 and EN 450 compressive strength requirements. Some mixtures required extra gypsum to address undersulfation, but this adjustment did not compromise overall performance. These findings highlight LC³-like cements as a sustainable alternative that reduces carbon emissions while maintaining strong performance.

Abstract #3465

Self-healing efficiency of artificial mineral aggregates in lime-pozzolana binder systems.

Adhora Tahsin and Warda Ashraf, The University of Texas at Arlington, Arlington, TX

Abstract Text:

This study investigates the effectiveness of artificial mineral aggregates in promoting self-healing in lime-pozzolana binder-based mortar when subjected to a marine environment. Two types of aggregate were developed: one made from metakaolin and hydrated lime and the other from calcium sulfoaluminate cement (CSA). The aggregates were prepared by palletization and coated with PVA. Each aggregate type was added at a dosage of 5% by mass of the binder in the mortar samples. The healing efficiency was evaluated by measuring strength recovery, the crack closure percentage, and in-depth crack filling using microCT observation. The healing product was identified through thermogravimetric analysis (TGA), Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM). After 28 days of curing in seawater, a single crack measuring 25 to 250 μm was created in all samples, and healing observations were made for the following 90 days. All the samples with and without mineral aggregates demonstrated a strength recovery of 3%~15% after 90 days of cracking, with the sample containing CSA-based aggregates showing the highest recovery. 100% crack closure was observed on the mortar surface, with narrower cracks (<200 μm) filling within 7 days. For wider cracks (>200 μm), a 50 to 90% healing efficiency was obtained within 90 days of seawater exposure. The observations of the crack extending into the depth of the sample indicated that CSA aggregates were the most effective in facilitating localized crack filling at the aggregate location. The healing products mostly observed were aragonite, calcite, hydromagnesite, nesquehonite, brucite, ettringite and Mg-Al-CI-LDH.

Abstract #3468

FAST-CO₂: Facilitating accelerated strength and transformation of concrete via regulated CO₂ mineralization with lime

Christie Arrington, Monica Amaral, and Jialai Wang, The University of Alabama, Tuscaloosa, AL

Abstract Text:

This study introduces an enhanced version of the BioCarb process, a cost-effective and sustainable method that accelerates cement hydration and improves strength through the carbonation of lime slurry. In this innovative approach, slaked lime slurry is combined with metakaolin and gypsum to further enhance the hydration process and significantly improve the mechanical properties of the mortar. Metakaolin, a highly reactive pozzolan, and gypsum, a well-established setting regulator, work synergistically to accelerate cement hydration, refine the microstructure, and increase compressive strength. Mortar specimens prepared using the BioCarb method exhibited a remarkable 50% increase in compressive strength within just three days, surpassing the performance of conventional methods. The

incorporation of metakaolin enhances pozzolanic reactivity, while gypsum optimizes setting time, contributing to the rapid strength development. This accelerated curing process, coupled with the environmental benefit of CO₂ sequestration, makes BioCarb particularly beneficial for industries that require fast turnaround times, such as precast concrete production. The study compares key factors such as hydration kinetics, workability, setting time, and mechanical performance, showcasing the ability of BioCarb with metakaolin and gypsum to enhance both construction efficiency and sustainability. The findings suggest that this approach not only improves the strength of cementitious materials but also offers a more sustainable alternative to traditional cement production methods.

Abstract #3470

Morphological control of magnesium silicate hydrates during aqueous synthesis

Vikram Gopalan and Erika La Plante, UC Davis, Davis, CA

Abstract Text:

Magnesium silicate hydrate (MSH) cements show promise as a less carbon-intensive alternative binder to calcium silicate hydrates. We have previously shown that MSH grows via nonclassical crystallization, both oriented and non-oriented attachment, and that its morphology is sensitive to reaction time, temperature, presence of organic additives, and spatial distribution. However, the driving forces behind the growth mechanism of MSH are still unclear. Understanding the precipitation pathway of concrete is critical because it ultimately controls its microstructural and property development. This study analyzes MSH samples grown on MgO crystals exposed to aqueous sodium metasilicate with varying substrate and solvent characteristics (e.g., deposited particles or adsorbed molecules on the MgO). Atomic force microscopy was employed to observe the influences on the nanoparticle formation and mesocrystalline organization in MSH on the scale of a few minutes to a few hours. Our findings suggest that the presence of adsorbed acetone and deposited silica particles promotes MSH to grow directionally from a nucleated cluster. Furthermore, these surface preparations appear to decrease the number of nucleation sites and promote growth on preexisting nuclei. These results imply that the growth of MSH can be controlled using the presence and availability of nucleation sites, and that it is possible to force MSH to primarily grow via oriented attachment. Effectively manipulating the morphology of MSH allows for control of how cement particles pack with one another, which can improve hydration rate, strength, and durability. Results from this study have implications in advancing MSH as a candidate as a cementitious material alternative.

Abstract #3477

Optimizing clay mineral dehydroxylation for energy-efficient supplementary cementitious material production: A kinetic and mechanistic approach.

Oluwadamilare Charles Adesina, Sayee Srikarah Volaity, and Narayanan Neithalath, Arizona State University, Tempe, AZ, Bryan K Aylas-Paredes and Aditya Kumar, Missouri University of Science and Technology, Rolla, MO, and Chengqing Qi, Ash Grove Cement Company, Overland Park

Abstract Text:

Reducing clinker content by incorporating supplementary cementitious materials (SCMs) is a key strategy for mitigating the 8 anthropogenic CO₂ emissions associated with cement production. Among SCMs, calcined clays—produced through the heat treatment of geologically abundant and cost-effective raw clays—play a pivotal role in low-carbon cement blends such as limestone-calcined clay (LC²) supplements and limestone-calcined clay cements (LC³). However, the lack of pre-requisite fundamental studies on clay dehydroxylation mechanism often leads to inefficient calcination protocols, with unnecessarily prolonged high-temperature treatments that compromise energy efficiency, material reactivity and the market viability of these cement blends. This study presents a robust kinetic analysis of kaolinite and montmorillonite (notable for their pozzolanic properties) dehydroxylation under linear non-isothermal temperature programs, employing advanced model-free methods that are devoid of computational approximations to ensure reliable predictions across a suitable temperature range for clay calcination. Activation energy and pre-exponential factor components of the kinetic triplet characterizing

the dehydroxylation reaction are determined using the Friedman differential and advanced Vyazovkin incremental isoconversional methods. The third component—the reaction model, identified using the master plot approach and kinetic compensation effect—reveals a reaction-order mechanism for kaolinite dehydroxylation, while montmorillonite exhibits a diffusion-controlled process from the crystallite perspective. The derived kinetic triplets are implemented to predict isothermal calcination conditions for the clay minerals, further validated through thermogravimetric (TGA) and X-ray diffraction (XRD) analyses. Additionally, the reactivity of the calcined clays is assessed using heat release rates of clay-portlandite blends from isothermal calorimetry within a thermodynamic framework. The developed framework provides a comprehensive foundation for optimizing calcination conditions of raw clays to maximize dehydroxylation, enhance reactivity, and improve energy efficiency while mitigating the risks of over-calcination in activated clays for sustainable cement replacements and/or cement manufacture.

Abstract #3481

Impact of calcium sources and bacterial strains on biomineralization-induced degradation of portland cement paste

Cansu Acarturk, Caitlin J. Adams, Isabel Popke Russell and Wil V. Srubar III, University of Colorado Boulder, Boulder, CO

Abstract Text:

Microbially induced calcium carbonate precipitation (MICP) presents a popular biological approach to enhance concrete sustainability and durability by mitigating crack-induced damage through biomineralization. While significant progress has been made in understanding MICP's crack-healing potential, the effects of treatments on the cement matrix remain underexplored, particularly regarding variations in media composition and bacterial strains. This study investigated the influence of biomineralization media, composed of three calcium sources (calcium acetate, calcium chloride, and calcium nitrate) and urea, on the chemical stability and mechanical properties of cementitious materials. The investigation further expanded to two bacterial strains, *Sporosarcina pasteurii* and *Lysinibacillus sphaericus*, to evaluate strain-dependent differences in biomineralization performance. For this work, ordinary portland cement (OPC) paste cubes were immersed in bacterial or abiotic treatment media with varying calcium and urea concentrations, with treatments reapplied three times weekly until testing at 7 and 28 days. Limewater served as a control treatment. At each testing day, pH and urea concentrations of the supernatant were measured to evaluate the bacterial activity and solution stability. Compressive strength of the treated cement paste samples assessed the mechanical performance and X-ray diffraction was utilized to characterize microstructural and chemical changes. Additionally, MICP yield in each sample was quantified using thermogravimetric analysis. Preliminary findings indicated that MICP activity is significantly influenced by both the calcium source and bacterial strain, impacting both the pH of the treatment environment and the extent of cement matrix degradation. Among the calcium sources, calcium acetate facilitated the highest MICP activity, while calcium chloride and calcium nitrate yielded lower precipitation. Samples treated with *Lysinibacillus sphaericus* showed slightly reduced compressive strength compared to those treated with *Sporosarcina pasteurii*. These results highlight the importance of optimizing MICP conditions to balance effective crack healing with the preservation of structural integrity.

Abstract #3483

Understanding phase evolution in hydrating belitic calcium sulfoaluminate cements via raman imaging

Momina Rauf and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

Upon hydration, the phase assemblage in CSA cements rapidly evolves in the first few hours. Understanding and predicting the nature of this hydrated phase assemblage is key to determining the performance of these cements in the real world. Recently, Raman imaging has been identified as a potential tool to quantify anhydrous CSA phases. However, its application in hydrated CSA systems

remains limited. In this study, we broaden the application of Raman imaging to analyze hydrated phase assemblages in Belitic CSA (BCSA) cement pastes. By combining Raman imaging with other complementary techniques like XRD, TGA, and Isothermal Calorimetry, we report reaction kinetics at various curing intervals (1, 3, 7, 14, and 28 days). In parallel, we perform compressive strength measurements on BCSA mortars at the same ages. Preliminary results indicate that we can link mineralogical evolution with some aspects of mechanical performance. Together, these results offer a more comprehensive and holistic picture of BCSA hydration.

Abstract #3485

Evaluating the suitability of emerging low-carbon materials as viable cement replacements

Abigail I Kienzie and **Sriramya D Nair**, Cornell University, Ithaca, NY

Abstract Text:

As the demand for sustainable construction materials grows, identifying viable low-carbon alternatives to traditional portland cement binders is crucial for reducing the environmental impact of concrete production. Emerging materials, including industrial waste byproducts, offer the potential to reduce portland cement consumption. This work seeks to characterize several emerging low-carbon materials, with a focus on the fundamental properties that determine their suitability for use as cement replacements. These factors include chemical and microstructural composition, reactivity, and the potential to influence mechanical properties such as compressive strength. This research provides insights into the potential for increased adoption of these materials and establishes a foundation for further testing on a larger scale.

Abstract #3486

Role of aggregate packing in enhancing concrete fracture response: Insights from in-situ high-speed imaging

Nischal Kanel, **Bayezid Baten** and **Nishant Garg**, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

Existing literature has focused on improving concrete's fracture response by studying binder composition. However, the critical role of aggregate packing in fracture response is often overlooked. Here, we use a continuous packing model to investigate the impact of aggregate packing enhancement on the fracture behavior of 4 unique concrete mixes, having customized aggregate skeletons. Fracture assessment using the two-parameter fracture model and high-speed cross-sectional digital image correlation was employed to capture strain distribution and crack propagation from 95% of the pre-peak to the peak load. We find that improving aggregate packing efficiency from 88% to 93%, with constant binder content, increased fracture energy (G_f) by 35.29% (3 days) and 39.48% (7 days), and critical stress intensity factor (K_{Ic}) by 46.08% (3 days) and 51.66% (7 days). The results quantify the impact of aggregate packing on concrete's fracture response paving the way for eco-efficient and resilient concrete without altering binder content.

Abstract #3489

Using 4D x-ray micro-CT to study self-healing in fiber-reinforced mortar containing fine olivine sand

Kaina Rodrigues Vieira and **Laura E. Dalton**, Duke University, Durham, NC

Abstract Text:

Portland cement production is a major contributor to global CO₂ emissions, responsible for nearly 8% of total emissions. Developing sustainable alternatives is crucial for reducing greenhouse gas emissions and construction-related environmental impacts. In this study alternative aggregates and optimized concrete

mixes designed to enhance CO₂ mineralization and promote self-healing properties are investigated. A direct comparison of fiber-reinforced mortar samples containing standard quartz sand and fibers, olivine sand (a magnesium-rich mineral), is assessed using standard compressive strength testing and 4D X-ray micro-computed tomography (μCT). Fracture patterns and self-healing potential were captured using high-resolution μCT. Preliminary results indicate that samples containing olivine and fibers exhibit a 9.3% increase in compressive strength compared to those with standard manufactured sand. Additionally, μCT analyses reveal early-stage mechanical self-healing potential, likely facilitated by the accumulation of fine particles sealing cracks. These findings suggest olivine-based concrete mixes could serve as a sustainable and durable option that would reduce repair needs while enhancing carbon sequestration with the magnesium-rich composition. Exposure to different CO₂ conditions is ongoing.

Abstract #3496

Value-added application of biochar for sustainable concrete pavement: Laboratory study and field demonstration

Jialuo He, Washington State University, Pullman, WA, **Xianming Shi**, University of Miami, Coral Gables, FL and James Amonette, Pacific Northwest National Laboratory, Tri-Cities, WA

Abstract Text:

This work aims to engineer biochar from waste biomass (primarily forestry residues and biosolids) for its incorporation in concrete and to develop durable, carbon-smart alternatives for a sector that is increasingly attracting attention for its carbon footprint. We explored in the laboratory the compressive strength and water absorption characteristics of paste, mortar and concrete composites incorporating either ground biochar or carbonated biochar. For instance, paste specimens with cement replaced by 10 wt.% properly ground biochar products A, B and C retained a 28-day compressive strength of 52 MPa, 43 MPa and 53 MPa, respectively. In contrast, only the mortar specimens with fine aggregate replaced by 10 wt.% carbonated biochar product C retained a 28-day compressive strength of 38 MPa, whereas their counterparts with products A and B only retained 15 MPa and 18 MPa, respectively. For concrete specimens, the control group without biochar exhibited a 28-day compressive strength of 38 MPa, whereas the groups with 5 wt.% ground biochar A or B (replacing cement) and 20 wt.% carbonated biochar C (replacing fine aggregate) retained 33 MPa or 36 MPa. Note that these concrete groups featured comparable initial water absorption rate, whereas the biochar-amended groups featured a secondary water absorption rate two to three times higher. We also conducted a cradle-to-gate environmental life cycle assessment (LCA) of the biochar-amended concretes mentioned above, one of which features a 52.4% reduction of equivalent CO₂ footprint, by replacing both 5 wt.% cement and 20 wt.% fine aggregate. Another concrete mixture becomes carbon-neutral by replacing 10 wt.% cement by ground biochar. This work also covers the field demonstration of biochar-amended concrete mixtures as a 135-foot sidewalk in the City of Bellingham, Washington, for long-term monitoring of concrete pavement performance in cold climates.

Abstract #3500

Evaluating the effectiveness of grinding aids and their water reducing capabilities for one-part alkali-activated calcined clay

Yangwoo Lee and Claire E. White, Princeton University, Princeton, NJ

Abstract Text:

Grinding aids are widely used in the cement industry, and their popularity has grown in response to modern demands for energy efficiency and carbon neutrality. However, commercially available grinding aids have been developed for Portland cement chemistry and as such their transferability to various types of alternative binder systems needs to be evaluated. Here, ongoing work has focused on evaluating the

effectiveness of existing grinding aids for one-part alkali-activated calcined clay, including their ability to enhance particle dispersion during grinding. This has been assessed via dynamic light scattering and associated quantification of particle size distribution. Moreover, their efficacy at reducing water demand in the resulting one-part pastes has been quantified. Zeta potential measurements of the calcined clays with and without grinding aids provide insight into particle surface chemistry in aqueous conditions and how these additives affect particle-particle interactions and associated tendency for agglomeration to occur.

Abstract #3506

Enhancing strength and reducing porosity via nucleation seeding

Faisal Qadri and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

C-S-H seeds are a new class of commercially available admixtures that serve as nucleation sites for additional hydration products. In the past decade, they have been used to enhance the early strength of concrete. While their impact on strength is well known, relatively little information is available about their influence on microstructure and porosity. In this talk, we will share our latest results on seeded mixtures where the porosity is examined by a combination of helium pycnometry as well as high-resolution confocal laser profilometry. Helium pycnometry reveals a clear reduction in open porosity proportional to the seed dosage. Moreover, laser profilometry reveals a microstructural refinement upon the addition of these C-S-H seeds. Together, these results provide strong evidence for porosity reduction in the presence of these C-S-H seeds, suggesting potentially enhanced durability.

Abstract #3510

Stereochemical biomimicry in cement science: Unraveling organic-inorganic interactions in calcium-silicate-hydrate formation

Sondos Hlayhel, Zahra Rouzitalab, Sarah Hlaihel, and Konrad J Krakowiak Dr., University of Houston, Houston, TX

Abstract Text:

The nucleation and growth of calcium-silicate-hydrate (C-S-H) govern the early-stage evolution of cementitious systems, influencing their long-term performance and durability. Inspired by biomineralization principles, this study explores the hypothesis that interfacial stereochemical effects dictate C-S-H nucleation, growth, and self-assembly in reactive organic-inorganic colloidal cement systems. To test this hypothesis, this work aims to (1) understand the structural and energetic attributes defining stereochemical matching between C-S-H and organic modifiers, (2) elucidate the molecular mechanisms governing C-S-H nucleation and growth kinetics, and (3) map the stereochemical pathways of C-S-H self-assembly in reactive organic-inorganic colloidal systems. The developed approach uses a combination of computational materials science (atomistic simulations) and an experimental approach, which will be the focus of the poster presentation. The proposed experimental approach employs the titration experiment in which C-S-H nucleation in the absence/presence of organic modifier is traced under various analytical conditions, e.g., pH level and temperature. The development of this experimental platform and reliable analytical protocols will be outlined, together with its relevance to studies of non-classical (NCN) nucleation of C-S-H. Moreover, results from the studies on the importance of pH on nucleation and C-S-H formation kinetics will be discussed and supported with the experimental titration curves. Finally, the direction of the ongoing work and its relevance to modern concrete technology will be highlighted.

Abstract #3514

CO₂ mineralization using MSWI ash as a low-carbon pathway of producing supplementary cementitious materials

Farzana Mustari Nishat and Warda Ashraf, The University of Texas at Arlington, Arlington, TX

Abstract Text:

This study investigated the potential of municipal solid waste incineration (MSWI) ash for carbon sequestration and its subsequent utilization as supplementary cementitious materials (SCM). Four carbonation methods were explored with variable liquid contents along with pH control. Carbon sequestration efficiency was assessed using thermogravimetric analysis (TGA) by measuring the conversion of carbonatable calcium oxide into calcium carbonate. Additionally, X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and inductively coupled plasma mass spectrometry (ICP-MS) were used to characterize the products of different methods. Results demonstrated significant variation in sequestration efficiency across different methods, with liquid carbonation without pH control achieving the lowest efficiency (2%), while multi-step pH-controlled liquid carbonation reached the highest efficiency (70%). Furthermore, the multi-step pH control facilitated the formation of amorphous silica-rich residues and high-purity calcium carbonate, making it a promising approach for repurposing MSWI ash as SCMs. These findings highlight the potential for sustainable MSWI ash management through carbon sequestration, contributing to both waste reduction and resource recovery.

Abstract #3526

Optimizing the CO₂ uptake and strength of foamed cellular concrete

Aysan Farajnia and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

Carbonation of conventional concrete is slow and surface-limited, whereas foamed cellular concrete (FCC) facilitates rapid CO₂ uptake through its porous structure. A major challenge with FCC is its reduced strength, which can be improved with CO₂ curing. This study systematically investigates FCC mix design with varying water-to-cement ratios (0.5, 0.6, 0.7) and densities (1000, 1300, 1600 kg/m³), under normal and accelerated CO₂ curing to optimize carbon sequestration and compressive strength. Our results indicate that the compressive strength of FCC can be increased by up to 100% through calcium carbonate precipitation during CO₂ curing. Further, CO₂-cured FCC achieves 3-day strengths comparable to or exceeding 28-day conventionally cured concrete. Raising the w/c ratio from 0.5 to 0.7 increases CO₂ uptake by ~15% at similar densities, while reducing density from 1600 to 1000 kg/m³ increases uptake by up to 25%. These findings highlight FCC as a promising low-carbon alternative with enhanced CO₂ uptake.

Abstract #3529

Time-dependent rheological behavior of cement paste containing calcined clay with respect to water-to-cement ratio

Sudipto Sarkar, Farzana Mustari Nishat, Nishad Ahmed and Warda Ashraf, The University of Texas at Arlington, Arlington, TX

Abstract Text:

Rheology plays a crucial role in modern construction, particularly in automated processes, where achieving optimal workability is essential. This study focuses on how rheological parameters of cement paste, such as yield stress and viscosity, evolve over time with respect to different water-to-cement (w/c) ratios and calcined clay contents. Paste samples with varying w/c ratios were prepared and tested over different resting times and analyzed using the Bingham model to obtain yield stress and viscosity, alongside hydration kinetics and microstructural analysis. Results indicate that increasing water content

reduces initial yield stress and viscosity, but both parameters evolve significantly over time due to ongoing physical and chemical changes. Lower w/c ratio mixes exhibit higher initial yield stress and viscosity, with minimal variation until the initial setting time, while higher w/c mixes start with lower values but show a continuous increase. The use of calcined clay at a fixed w/c increases the initial viscosity and yield stress while reducing the time dependent variations. By optimizing w/c ratio, SCMs, and chemical admixtures, the rheological evolution of cement paste can be controlled to ensure a balance between open time and workability, minimizing delays while meeting specific construction demands.

Abstract #3530

Sustainable geopolymers concrete: Optimizing calcined clay and hemp hurd for green construction

Christopher Vreeland and Maryam Hojati, University of New Mexico, Albuquerque, NM

Abstract Text:

Geopolymer concrete (GPC) is emerging as a sustainable alternative to traditional Portland Cement concrete (PCC), offering superior mechanical and durability properties, including enhanced fire resistance, chemical resistance, and reduced moisture absorption. Unlike PCC, which relies on calcium and generates significant CO₂ emissions during manufacturing, GPC utilizes silica and aluminum, thereby reducing waste gas production. Additionally, most GPC mixes depend on industrial byproducts like fly ash, which face declining availability due to the shift away from coal-fired power plants. This research addresses these challenges by exploring calcined clay as a precursor for GPC. Using two commercially available calcined clays, MK828 and MetaForce, mix design and mixing methods were optimized to create stable and strong cementitious binders. Successful cement pastes were reached over 6600 psi and 7100 psi, respectively. It was found that MK828 required more water and alkalinity inputs to gain equivalent strength of MetaForce mixes. Above certain activation thresholds, increasing molecular Si:Al ratios showed positive correlation with compressive strength for both precursors. Conversely, workability began to suffer with the associated decreasing Al:Na ratios. One cement paste of each powder was selected to carry into the second research phase.

Next, this research innovatively pairs calcined clay with hemp hurd to develop two types of construction composites: a high-fiber-content mix for insulation applications similar to hempcrete, and a low-fiber-content mix designed to meet concrete masonry unit performance standards. Variables examined include cement binder, fiber content, and fiber type. Measured parameters include compressive and flexural strength values for each configuration. This novel composite not only advances sustainable construction materials but also opens new avenues for advancement in geopolymer technology. By leveraging calcined clay and hemp hurd, this research offers a pathway to reduce the environmental impact of concrete production while maintaining performance, paving the way for greener infrastructure solutions.

Abstract #3533

Onset heat size index – a parameter to predict the rheology of calcined clays

Muhammad Farjad Iqbal and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

Calcined clays have emerged as a viable alternative to traditional SCMs due to their potential to enhance the durability and sustainability of concrete. However, their high-water demand often leads to significant workability challenges. We analyzed the rheology and strength evolution of 16 cement-clay blends and observed a wide range of yield stress (30–350 Pa). Calorimetry results further reveal that rheological properties are intrinsically linked to the onset heat of hydration. Leveraging this insight, we introduce a new parameter, the Onset Heat Size Index (OHSI = $OH / (OT \times \text{Particle Size})$), which integrates calorimetric and particle size distribution data for the first time. This index effectively predicts yield stress ($R^2 = 0.86$, RMSE = 34 Pa), demonstrating its potential as a practical tool for simultaneously assessing the reactivity and rheology of cement-clay blends using widely adopted characterization techniques.

Abstract #3538

Carbonated recycled cement paste: CO₂ uptake and reactivity

Kingshuk Mukherjee and Prannoy Suraneni, University of Miami, Coral Gables, FL

Abstract Text:

The concrete industry is a significant contributor to global CO₂ emissions, primarily due to the calcination of limestone in clinker production. Recycled cement/concrete products offer a scalable pathway to mitigate the CO₂ emissions of the concrete industry. We investigate here the upcycling of recycled cement paste (RCP) as a supplementary cementitious material (SCM) or filler through controlled carbonation. Several RCP materials with varied SCMs are exposed to CO₂. We show that in SCM systems, phases other than calcium hydroxide are also carbonated, and the CO₂ uptake remains high, in spite of SCM substitution. The carbonated RCPs showed minimal levels of reactivity, suggesting that they are better suited to be filler materials rather than SCMs.

Abstract #3552

Rheological and mechanical properties of carbon-negative 3D printed concrete using functionalized biochar

Nishad Ahmed and Warda Ashraf, The University of Texas at Arlington, Arlington, TX

Abstract Text:

3D concrete printing (3DCP) is an innovative technology with the potential to revolutionize the construction industry, and recently, the incorporation of biochar in 3DCP has gained significant attention due to its ability to reduce the carbon footprint of cement-based materials by sequestering carbon and enhancing the sustainability of concrete. This study explores the potential application of biochar addition in cementitious composites to produce carbon-negative 3D-printed concrete. Functionalized biochar was added to a blended binder containing ordinary portland cement (OPC) and blast furnace slag cement at a 1:1 ratio. The biochar amounts were calculated based on the target zero carbon footprint of the composites. This study investigated the impact of adding biochar and partially replacing the blended binder with medium-grade calcined clay on the workability, buildability, rheological, and mechanical properties of the 3D-printed concrete. Findings revealed that the increasing dosage of biochar and clay enhanced the buildability of 3DCP while reducing its open time. However, the surface smoothness of 3D printed materials was improved for lower dosage clay and biochar batches. The compressive strength of the carbon-negative batches was increased up to 44% compared to the control batch (without biochar and clay). The superior properties of functionalized biochar were due to their ability to the cement hydration and densification of the composites. The life cycle assessment (LCA) showed that the addition of biochar reduced the global warming potential (GWP) by up to 130% compared to the control batch.

Abstract #3559

Raman imaging for advanced characterization: From cement hydration to ASR

Chirayu Kothari and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

The drive toward sustainability has resulted in complex cement formulations that exhibit significant variability in mineralogical phases, chemical compositions, and particle sizes, affecting the workability, strength, and durability of concrete. Characterizing these properties is challenging and requires various techniques such as microscopy, spectroscopy, and diffraction. Raman imaging is a versatile technique for investigating the cement lifecycle—from anhydrous cements to hydration and long-term durability. Here, we emphasize the complementary nature of Raman imaging in identifying and quantifying Type I/II OPC and CSA cements, demonstrating a strong agreement ($R^2 > 0.99$, $\Delta \text{wt.}\% < 5\%$) with XRD. Secondly, we investigate and report the microstructural mapping of hydrated cements. Finally, we illustrate the use of Raman imaging in mapping the Alkali-Silica Reaction (ASR) within cementitious systems, distinguishing

between the presence of ASR gel (Q^3 sites) and C-S-H gel (Q^2 sites). These results highlight the versatility of Raman imaging in characterizing a broad variety of cementitious systems.

Abstract #3572

Closing the silica loop in concrete recycling: High performance silica gel synthesized from hardened cement paste.

Abdulmaliq Alawode, Jialai Wang, Xiaodong Wang, Xi Chen, Maysam Bahmani, Monica Amaral and Aniket Patnaik, The University of Alabama, Tuscaloosa, AL

Abstract Text:

Making improved concrete out of concrete wastes is a viable and effective sustainable method of recycling and upscaling benefits from concrete wastes. The production of concrete wastes from various sources tremendously increases annually with no substantial value-added impact. Therefore, this study focusses on effective utilization of concrete wastes to improving their end-of-life efficiency. The morphology, composition, pozzolanic reactivity, and mechanical performance of the recycled silica gel were critically examined at different treatment levels. At a 15% cement replacement, the recycled silica gel significantly enhanced mechanical performance by up to 148% after 28 days. The results further demonstrate that this technology effectively modifies the silica structure of the hydrated cement products, making it a highly efficient supplement for secondary reaction during cement hydration.

Abstract #3585

Measuring total sulfur content of reactive aggregates using electron probe microanalysis free from matrix interference.

Dip Banik and Alexander S. Brand, Virginia Tech, Blacksburg, VA

Abstract Text:

Sulfur, one of the most abundant elements in earth's crust, exhibits varying oxidation states from -2 to +6. Certain sulfur-containing minerals, such as pyrrhotite ($Fe_{1-x}S$) and framboidal pyrite (FeS_2), possess non-stoichiometric ratios or poor crystallinity. In the presence of suitable conditions (oxygen and moisture), these minerals can oxidize, causing volumetric expansion. When present in concrete aggregates, this expansion, along with secondary sulfate attack, leads to concrete degradation. To mitigate this, European Standard EN 12620 and the Massachusetts Department of Transportation recommend sulfur content limits of 1.0% for all aggregates and 0.1% when pyrrhotite is identified.

Common sulfur detection techniques include acid digestion (AD), x-ray fluorescence (XRF), and high-temperature combustion (HTC). AD, involving sulfur dissolution in heated hydrogen peroxide and hydrochloric acid mixture, is time-consuming, hazardous, and may underestimate sulfur due to hydrogen sulfide gas loss. Though XRF and HTC are simpler and faster, they require matrix-matched references for accurate measurements. This can hinder the practicality as sulfur-bearing minerals are present in numerous different matrices. To overcome these limitations, this study employs standardless electron probe microanalysis measurements. Unknown samples doped with varying iron sulfide (FeS) contents were micronized to a 5-micron median particle size, embedded in epoxy, and analyzed using wavelength-dispersive spectrometry. Sulfur characteristic x-rays were detected at random locations, and statistical analysis of sample counts with and without iron sulfides enabled sulfur quantification. This method effectively determines total sulfur content without matrix interference, making it a viable standard detection technique.

Abstract #3586

Early age strength enhancement of high SCM mixes

Muhammad Ayyan Iqbal, Bayezid Baten and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

High supplementary cementitious material (SCM) blended mixes enhance the sustainability of concrete but often reduce early-age (1-day) strength. While accelerators can mitigate this issue, the optimum dosage for different SCM systems remains unclear. This study systematically investigates the performance of seven accelerators — calcium chloride, potassium sulfate, calcium nitrate, calcium nitrite, and 3 different commercial C-S-H seeds— across fly ash and slag blended systems. Preliminary results show that for optimum accelerator dosages, 1-day compressive strength gain increases with fly ash content, peaking at 40% SCM dosage. Strength improvement ranges from 20% for 1% calcium nitrate to 85% for 0.25% C-S-H seeds. Notably, 1% calcium nitrate and 0.25% C-S-H seeds achieved 11 MPa and 17 MPa respectively, exceeding the 10 MPa requirement for high early-strength cement per ASTM C1157. Together, these findings enable the selection of accelerator types and dosages for designing low-carbon concrete mixes while maintaining early strength.

Abstract #3592

Development of 3D printable lightweight concrete with granulated cork: A novel mixture design method considering aggregate water absorption in cementitious suspensions and rheological performance

Hanbin Cheng, Aleksandra Radlińska, Jose Pinto Duarte, Ali M. Memari, and Sven Bilén, Pennsylvania State University

Abstract Text:

In this study, a novel mixture design approach was developed to produce 3D-printable lightweight concrete incorporating granulated cork. First, a linear correlation between cement paste expansion and the optimal cork aggregate content was established to satisfy both flowability and buildability requirements for 3D-printed concrete. In addition, the relationship between the dynamic yield stress and the water-to-binder ratio of the paste was determined. To broaden the applicability of this approach to various cork aggregate types with different water absorption capacities, the water absorption behavior of various granulated cork aggregates in cementitious suspensions was investigated. The findings revealed that oven-dried cork aggregates reach an equilibrium saturation state within the cementitious suspension during mixing, rather than achieving a surface-saturated state. Then, the influence of cork aggregate water absorption on the rheological performance of the cement paste was quantified using the Chateau–Ovarlez–Trung model. Subsequently, a water loss factor—quantifying the paste loss resulting from cork water absorption—was introduced to modify the calculation of the excess cement paste thickness. Verification tests confirmed the efficacy of the proposed linear relationship, and the revised cement paste thickness theory in designing 3D-printable lightweight concrete mixtures, while simultaneously accounting for the water absorption capacity and particle size distribution of the granulated cork aggregates.

Abstract #3601

Effectiveness of ground tire rubber to replace air-entraining agents to mitigate freeze-thaw damage in pavement concrete

Samantha Young, John Myers, and Dimitri Feys, Missouri University of Science and Technology, Rolla, MO, Parisa Nemati and Ceki Halmen, University of Missouri Kansas-City, Kansas-City, MO and John Kevern, University of Missouri Kansas-City, Kansas-City, MO and National Renewable Energy Laboratory, Golden, CO

Abstract Text:

The freeze-thaw durability of concrete is highly dependent on the entrainment of air bubbles, most commonly achieved using chemical admixtures. However, the ability of conventional air entraining admixtures to consistently provide appropriate and stable air systems is challenged by new cement chemistries and supplementary cementitious materials. One approach to address the challenge presented by consistently entraining air with highly variable cementitious mixtures is the incorporation of physical air entrainment. One option to provide physical air entrainment is utilizing crumb rubber. This

study explores the use of crumb rubber for freeze thaw durability of concrete pavements. Samples were produced containing three different particle sizes of rubber as well as differing percentages of rubber in the mixtures for comparison against samples containing conventional, surfactant-based air void system. The samples were tested for strength and freeze thaw durability. The current results show rubber entrains air inside the concrete, and as expected, with a decline in strength. Freeze-thaw and scaling resistance results, as well as rubber and air-void distributions are discussed in the presentation. Additional research will be done to more accurately determine what components are contributing to the effects of performance and if the rubberized mixture could be scaled to large productions.

Abstract #3611

Exploring biopolymer-coated channels for microbial encapsulation in self-healing concrete

Sarah J. Willmann, University of Colorado Boulder, Boulder, CO and Duke University, Durham, NC, and Caitlin J. Adams, Samuel J. Armistead and Wil V. Srubar III, University of Colorado Boulder, Boulder, CO

Abstract Text:

Due to the significant environmental impact of concrete and cement production, extending the lifespan of existing buildings through proactive and sustainable maintenance strategies is essential. One emerging approach to prolong the service-life of concrete structures is microbially induced precipitation, which enables cracks to “heal” through biomineralization. However, a key challenge lies in ensuring the long-term survival biomineralizing microorganisms in concrete’s harsh, high pH environment. One potential solution is to form a barrier between these microorganisms and the concrete *via* encapsulation within biopolymer-coated channels, where they remain protected until activated by a cracking event. This study evaluates various biopolymers—including waste biomass, natural biopolymers, and synthetic polymers—for their potential as protective coatings in microbially induced precipitation (MIP)-based crack repair. To assess their suitability, film formation was characterized through qualitative assessment, gravimetric analysis, biopolymer composition assay, FTIR spectroscopy, and, where possible, tensile testing. Across nearly all extraction conditions, waste biomass-derived films exhibited the most promising characteristics, with NaOH-prepared films demonstrating measurable tensile strength. Notably, the tensile strength of testable waste-biomass films was comparable to that of typical concrete, suggesting sufficient mechanical durability for integration into self-healing concrete systems. These findings highlight the feasibility of biomass-derived biopolymers as sustainable encapsulation materials, with the potential to provide a protective environment for biomineralizing organisms, thereby enhancing the efficiency of MIP-based crack repair strategies and contributing to the development of sustainable self-healing concrete.

Abstract #3612

Scalable and transportable thermochemical energy storage using cementitious materials

Paul Ginsberg, Lakshmi Amulya Nimmagadda and Arpit Dwivedi, Cache Energy

Abstract Text:

Energy storage based on reversible chemical reactions, termed thermochemical energy storage (TCES), has been proposed since the 1970s. TCES based on calcium oxide and hydroxide, where dehydration of Ca(OH)_2 to CaO (lime) stores energy and the hydration of CaO to Ca(OH)_2 releases the energy, is especially promising. The material is cheap at \$100/ton, the reaction has high energy density at ~500 (W·h)/kg and is highly reversible, and the reaction temperatures of >550 °C can serve ~75% U.S industrial process heat demand. Additionally, the temperatures are high enough to drive efficient heat-to-power conversion cycles for electricity generation. However, commercialization of TCES has been hindered due the challenging nature of the material. Key among these is the high volumetric change of >150% during the charge/discharge process. This leads to steady breakup into a fine powder which can then agglomerate and limit mass transfer, causing a decay in capacity with cycling. We have explored various cement-based binders to provide strength and structural stability during high temperature cycling of lime. More than 1000 cycles with full capacity retention was achieved, with the microstructure tuned to provide high strength. The cycling performance was highly sensitive to processing conditions, including water content, pellet density, and curing time/temperature. A minimum water content at ~40 wt% was

found necessary and the cycling performance first improved and then worsened with increasing water content. In summary, the application of cement binders for energy storage requires research and development beyond conventionally optimized cement properties.

Abstract #3619

Effect of y-type zeolites on gaseous mineralization in portland cement

Angus B Moore, Atolo A Tuinukuafe and Jessica M Rimsza, Sandia National Laboratories, Albuquerque, NM

Abstract Text:

Supplementary cementitious materials (SCMs) such as silica fume, fly ash, and natural pozzolans are often used in hydraulic binders since they can improve or maintain performance while decreasing cost. While the mineral forming reactions of hydraulic binders are generally promoted by moisture, recent studies have shown that gaseous curing of portland cement can produce dense binding phases like calcite when appropriate concentrations of CO₂ and water vapor are used for curing. Zeolites are an intriguing SCM for this new curing approach since they offer both the chemical composition to facilitate pozzolanic reactions as well as a nanoporous channels that can facilitate transport of water vapor and/or CO₂. Two synthetic zeolites, containing either sodium or hydrogen cations, were used as SCMs in this study to evaluate the effect of cation-type on the performance in portland cement paste prepared via gaseous curing. The mechanical properties of samples were evaluated using ultrasonic pulse velocity (non-destructive) and splitting tensile (destructive) tests. X-ray diffraction, thermogravimetric analysis, mass spectrometry, and pH indicator methods were used to measure the extent of gaseous mineralization. Zeolite-containing samples displayed increased mass gain during curing and maintained mechanical performance at lower cement replacement levels. Further work is required to determine the effect of zeolites on reaction kinetics at earlier ages, as well as Poisson's ratio in this new type of high-performance cement composite. *SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.*

Abstract #3624

Investigating the effect of high and very high amount of scms on CO₂ uptake of mortars

Iman Aghajanzadeh, Montale Tuen, Prannoy Suraneni and Landolf Rhode-Barbarigos, University of Miami, Coral Gables, FL

Abstract Text:

This study investigates the effect of replacing 40% and 60% of cement by weight with fly ash and calcined clay, as supplementary cementitious materials (SCMs), on the CO₂ uptake of mortars used for marine infrastructure. After 28 days of curing in a moist room, samples were exposed to carbonation curing in a CO₂ chamber at 50°C, 20% CO₂ concentration, and 73±10% relative humidity. Bulk electrical resistivity, thermogravimetric analysis (TGA), and measurement of the carbonated area using phenolphthalein were conducted. The results show that incorporating SCMs increases carbonation extent. This occurs because the C-S-H formed by pozzolanic reactions absorbs more alkali ions, thereby decreasing the pH level. Samples with 60% SCMs exhibited nearly identical CaCO₃ content in both the surface and bulk, indicating full carbonation. CaCO₃ amounts were lower in mortars with SCMs than without, however, higher than expected if only the calcium hydroxide had carbonated. Additionally, incorporating SCMs increased the bulk electrical resistivity of the samples before carbonation, due to pore structure refinement and alkali binding in the pore solution. However, carbonation of C(-A)-S-H led to pore coarsening and increased capillary porosity, which was associated with carbonation shrinkage and cracking. As a result, the electrical resistivity of the samples containing SCMs was lower than that of the control mortar after carbonation.

Abstract #3625

Evaluating the effect of waste bovine bone as a fine aggregate substitute in cement mortar

Lamiya Noor and Wil V. Srubar III, University of Colorado Boulder, Boulder, CO

Abstract Text:

Bovine bone (BB) is a significant waste stream produced by the rendering industry, which is typically deposited in landfills, contributing to environmental pollution and increased CO₂ emissions. Utilizing such waste in concrete presents an opportunity to address the dual challenges of managing escalating waste volumes and developing sustainable, bio-derived construction materials. This study investigates the feasibility of incorporating BB as a fine aggregate replacement in mortar mixtures. Two BB-based mortar mixtures, water-saturated (PS) and non-water-saturated (NPS), with replacement levels of 0%, 1%, 5%, 10%, 15%, 25%, 50%, 75%, and 100%, were prepared and the fresh, hardened, and microstructural properties assessed. At 1% BB replacement mixtures achieved ~4000 psi, making them suitable for all structural applications. However, compressive strength and density decreased at higher BB content, with 5% and 10% BB mixtures achieving ~2400 psi. Results indicated that BB addition reduced the pH of the pore solution due to organic content dissolution in the alkaline cementitious environment. Energy-dispersive spectroscopy (EDS) analysis also revealed minimal impact on C-S-H composition up to 50% sand replacement by BB, but a declining Si/Ca ratio was observed when the replacement level increased to 75–100%. Scanning electron microscopy (SEM) confirmed weak interfacial zones between BB and cement paste, which corroborated the observed reduction in strength and density. These findings showed potential that waste BB, in controlled proportions, can be a viable alternative to fine aggregate in concrete.

Abstract #3634

Practical implementation of superabsorbent polymers (SAP) for internally cured concrete

Kendra A. Erk, Chibueze Ajuonuma, Raikhan Tokpatayeva, and Jan Olek, Purdue University, West Lafayette, IN

Abstract Text:

In collaboration with a local ready-mixed concrete company, a year-long field trial was performed to evaluate the performance of concrete internally cured with commercially available superabsorbent polymer (SAP) and colloidal nanosilica solutions. SAP was added to the concrete mixtures by dissolvable bags containing 1 pound of dry SAP particles, at a dosage of 1 bag per cubic yard of concrete (dosage of 0.15% SAP by weight of binder). All mixtures were 0.44 w/c using local Type II cement. Plain cement and slag cement (30% replacement) concrete that was internally cured by SAP had increased strength and durability compared to SAP-free concrete, concrete containing nanosilica, or concrete that was externally cured with a surface-applied curing compound. Key findings were the following: (1) SAP-cured mixtures displayed reduced slump and air content compared to SAP-free mixtures. However, all mixtures were within the target slump and air content values so no additional mixture adjustments were needed. (2) Mixtures containing SAP demonstrated improved early-age flexural strength performance compared to SAP-free mixtures. The addition of SAP also counteracted the early-age strength reduction caused by the use of slag. (3) The addition of SAP to both plain and slag cement concrete resulted in significant increases in compressive strength both at early and later ages when compared to the SAP-free reference mixtures. (4) When compared with using a surface-applied curing compound, the addition of SAP significantly improved the compressive strength of field cast and cored samples by more than 30-50% across all ages compared to SAP-free plain cement reference mixtures with and without curing compound. (5) Concrete mixtures incorporating SAP and slag consistently showed improved performance in comparison with the mixtures only containing SAP.

Abstract #3644

Magnesium effects on clinker composition and reactivity

Angélica Giraldo-Salazar, Carlos Orozco and Natalia Betancur-Granados, Research & Development, Cementos Argos S.A., Medellín, Colombia

Abstract Text:

Reducing CO₂ emissions is one of the main challenges in the cement industry, with 60% of these emissions resulting from the decarbonation of calcite during clinker production. One of the strategies to reduce the environmental impact is the reduction of clinker factor, which requires the increment of reactivity of clinkers produced. This research evaluates industrial samples of cements and clinkers with Al₂O₃ content around 5 to 6% and C₃A ranging between 2-9%, a component known to impact cement properties including early strength, setting times and heat evolution. The samples were characterized using X-ray diffraction (XRD), X-ray fluorescence (FRX), microcalorimetry and compressive strength. Results shows a reduction in C₃A with an increment in C₄AF connected with the increment of MgO in clinker, that turn in a control of calcium aluminate phases. Similarly, an increase of magnesium led to higher C₃S levels and lower C₂S content, an effect attributed to the mineralizing and fluxing properties of this compound, resulting in enhanced clinker reactivity. Additionally, through microcalorimetry variations in setting time and sulfate requirement were observed.

Abstract #3647

Understanding impact of calcination time on clay dehydroxylation via in-situ TEM

Tausif E Elahi, Pablo Romero and Nishant Garg, University of Illinois at Urbana-Champaign, Urbana, IL

Abstract Text:

Obtaining metakaolin of optimal reactivity requires careful selection of two parameters: calcination temperature and time. While significant literature exists on temperature-induced changes, the influence of time on dehydroxylation remains less explored, particularly at the particle scale during calcination. Here, we report preliminary results on the morphological changes that occur in individual clay particles upon dehydroxylation via in-situ Transmission Electron Microscopy (TEM) by observing kaolin particles on a live heated stage. The progression of dehydroxylation is monitored by acquiring the electron diffraction pattern at regular intervals enabling measurement of time required for complete dehydroxylation. These time-dependent kinetics of dehydroxylation are correlated with reactivity measured by the R3 tests revealing an exponential trend that saturates after a specific time. Our findings demonstrate that prolonged calcination time impacts particle morphology that subsequently enhances the pozzolanic reactivity of clays.

Abstract #3653

Preliminary study on real-time monitoring of bulk water movement in subzero-exposed portland cement concrete microstructure using neutron radiography

Md Hasibul Hasan Rahat, Dip Banik, Sepehr Akhtarshenas, Sherif L. Abdelaziz, and Alexander S. Brand, Virginia Tech, Blacksburg, VA, and James R. Torres and Yuxuan Zhang, Oak Ridge National Laboratory, Oakridge, TN, and Stefan Jacobsen, Norwegian University of Science and Technology, Trondheim, Norway

Abstract Text:

This study aims to enhance the understanding of freeze-thaw damage mechanisms by monitoring bulk water movement within concrete macropores exposed to subzero temperatures. The insights gained will contribute to developing more resilient infrastructure in cold regions and the Arctic. The research began with experimental planning at the MARS HFIR beamline CG-1D, where concrete sample thickness was characterized and optimized. Neutron radiography was utilized to investigate water movement within concrete macropores during the cooling process from 1D at -12.5°C, with embedded sensors measuring

temperature changes. The experimental setup included sealing samples, embedding sensors, regulating temperature with an external chiller, and capturing 2D radiographic images at 90-second intervals. A series of microstructural and mechanical analyses were conducted to further understand hydration kinetics, pore structure, freezing behavior of pores, and mechanical properties. These included isothermal calorimetry, thermogravimetric analysis, X-ray diffraction, low-temperature differential scanning calorimetry, N₂ gas adsorption, hardened air-void system analysis, and compressive strength. The analysis of neutron radiography data involves image reconstruction, segmentation, and quantitative and temporal analyses to provide insights into water movement within the concrete microstructure at subzero temperatures. The findings will aid in optimizing concrete durability, improving climate resilience in construction practices, and advancing material science to enhance infrastructure performance under various environmental conditions. Ultimately, this research aims to contribute to developing more durable and resilient concrete infrastructure in cold and Arctic regions.

Abstract #3660

Roles of tannic acid in the carbonation process of cement slurry

Xiaodong Wang, Monica Amaral, Abdulmaliq Alawode, Xi Chen, Maysam Bahmani and Jialai Wang, The University of Alabama, Tuscaloosa, AL

Abstract Text:

CO₂ can serve as a novel ingredient in concrete through a two-step mixing process. First, CO₂ is bubbled into a cement slurry, transforming it into an efficient CO₂ absorbent. The carbonated slurry is then mixed with other ingredients to produce concrete. Since carbonation and hydration of cement occur simultaneously, an admixture is introduced to regulate these reactions. In this study, tannic acid is selected as the admixture to enhance hydration and inhibit undesired reactions. Systematic experimental studies reveal that tannic acid significantly boosts CO₂ uptake, accelerates calcium carbonate phase transformation, and promotes the formation of calcite. In contrast, a mix of calcite and aragonite forms in the absence of tannic acid. Furthermore, tannic acid facilitates C-S-H carbonation, leading to the formation of a highly reactive silica gel. Consequently, the compressive strength of the resulting cement mortar is substantially improved. These findings suggest that regulating the carbonation process with tannic acid can greatly enhance both the carbon storage capacity and mechanical performance of concrete, offering a promising strategy for concrete decarbonization.

Abstract #3661

Enhanced CO₂ sequestration and strength of cementitious materials using a cost-effective renewable admixture

Aniket Patnaik, Jialai Wang and Monica Amaral, The University of Alabama, Tuscaloosa, AL

Abstract Text:

CO₂ mineralization presents a promising pathway for sequestering CO₂ in concrete, enhancing its performance, and reducing its carbon footprint. This study explores a cost-effective, naturally occurring molecule as a renewable admixture to regulate CO₂ mineralization in cement slurry. The aim is to enhance CO₂ uptake while controlling the formation of carbonation products. Preliminary evaluation of mortar samples prepared with this approach demonstrated significant improvements in workability and mechanical properties, with compressive strength increases of up to 46% after seven days. These findings suggest that regulating the mineralization process with a small-dose admixture is a promising strategy for boosting binder efficiency and reducing clinker demand in sustainable concrete production. Ongoing research aims to further elucidate the microstructural evolution of materials produced through this innovative approach.

Abstract #3663

Exploring the impact of carbonation in uncalcined and calcined clay-cement composites

Brittney D Seaburn, Chven Mitchell, Melissa Mills and **Jessica M Rimsza**, Sandia National Laboratories, Albuquerque, NM

Abstract Text:

Substitution of cement clinker by alternative supplemental cementitious materials (SCMs) such as silica fume, fly ash, or metakaolin is an active area of research to limit clinker content and use locally available or waste materials to offset cost and emissions concerns surrounding the use of Portland cement. With this uptick in binder innovation, uncalcined chemically modified clays have been identified as an available source for cement substitution. In this study, we explore how a 5% substitution of Portland by uncalcined chemically modified smectite clay materials impacts carbonation for binders and those containing the common supplemental cementitious material metakaolin. Samples were cast and cured for 28 days, conditioned in an NH_4NO_3 environment to stabilize at 66% relative humidity (RH), and carbonated for 14, 28, 56 and 112 days in a carbonation chamber at $\sim 24^\circ\text{C}$, $\sim 75\%$ RH, and 3% CO_2 concentration. Progression of the carbon front and mineralogical analysis of the carbonated and uncarbonated regions of the samples were performed, along with analysis pre- and post-carbonation using a 3D X-ray microscope (XRM). Results indicated rapid increase in carbonation beyond 56 days and sensitivity of carbonation rate to smectite clay compositions. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

Abstract #3665

A review of embodied carbon emissions and carbon sequestration potential of biochar-modified concrete

Austin Dada and Wil V. Srubar III, University of Colorado Boulder, Boulder, CO

Abstract Text:

The built environment accounts for over 45% of global CO_2 emissions and generates approximately 3 gigatonnes of construction waste annually. Concrete is a major contributor to both waste and emissions, largely due to the high resource and energy demands of cement production. Biochar, a carbon-negative material derived from the pyrolysis of organic feedstock, has recently been explored as a supplementary cementitious material (SCM) for its potential to reduce cement consumption, sequester carbon, and lower the environmental impact of concrete. However, no comprehensive review has compared biochar derived from different sources and its effects on the mechanical and environmental performance of concrete. This study examines various biochar SCMs used in concrete, mortar, and cement paste mixtures, assessing their impact on mechanical properties (e.g., compressive and tensile strength), upfront embodied carbon emissions, and carbon sequestration potential. While no statistically significant correlation was found between compressive strength and total upfront embodied carbon, rice husk ash biochar generally exhibited lower embodied carbon per unit megapascal increase in strength. These findings provide insights into the mechanical and environmental performance of biochar SCMs and inform future research on their potential for sustainable concrete applications.

Abstract #3670

Effects of nano-ettringite on the carbonation resistance of ordinary portland cement (OPC) and calcium sulfoaluminate (CSA) cement pastes

Rupack R. Halder, Titus C. Egbosiuba, Hongyan Ma and Monday U. Okoronkwo, Missouri University of Science and Technology, Rolla, MO

Abstract Text:

This study investigates the effect of nano-ettringite on the carbonation resistance of Ordinary Portland Cement (OPC) and Calcium Sulfoaluminate (CSA) cement pastes. While nano-ettringite has been shown

to enhance early-age properties, its impact on durability remains unexplored. Cement pastes with 5% nano-ettringite were cured for 28 days and then exposed to 3% CO₂ (55% RH, 20°C) for 30 days. Carbonation depth was measured using the phenolphthalein method, total carbonation was quantified via thermogravimetric analysis (TGA), and phase assemblages were analyzed using X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR). Microstructural evolution was examined via X-ray micro-computed tomography (μ CT), while residual compressive strength was tracked throughout carbonation. Results show that nano-ettringite reduced carbonation depth in both cement types, with OPC improving from 0.647 mm to 0.568 mm and CSA from 6.990 mm to 6.659 mm. Nano-ettringite-modified OPC showed a slight strength gain under carbonation, while CSA pastes initially strengthened but later returned to baseline. These findings suggest that controlled carbonation can enhance the performance of nano-ettringite-modified cements, though prolonged exposure may affect mechanical integrity. This study highlights nano-ettringite's potential as a durability-enhancing additive for cementitious materials.

Abstract #3672

Methane Pyrolysis-coproduced Carbon Nanotubes in Cementitious Materials toward Sustainable Construction and Hydrogen Production

Stuart McElhany, Anushree Konwar, Xiaohong Zhu, Carlo Carraro, Roya Maboudian and Paulo J.M. Monteiro, University of California, Berkeley, Berkeley, CA

Abstract Text:

Methane pyrolysis (MP) is a promising method to produce hydrogen with no reaction-based carbon dioxide emissions. Scaling up MP to meet current hydrogen demands would generate a massive amount of carbon coproduct which may be amenable to sequestration in cementitious materials like concrete. For the first time, the mechanical properties of cementitious composites incorporating carbon nanotubes (CNTs) coproduced from an operating methane pyrolysis plant are characterized. Compressive and tensile strength tests alongside rheological tests are conducted on mortars and pastes in which Portland cement has been replaced by various amounts of MP-derived CNTs from 0 to 1% by weight. The addition of these CNTs has a slight accelerating effect, mildly increasing the early-age compressive strength of the CNT-cement composites. The fresh properties of CNT-cement composites are significantly affected with a large increase in yield stress as high as 74.2% greater for a paste replacing cement in the amount of 1% (wt.) with CNTs relative to a plain cement paste. A life cycle assessment indicates that cementitious composites may be used to sequester MP-coproduced CNTs to reduce the environmental impact of the concrete industry, but large-scale implementation of such a system would be difficult in its current state as-tested.

Abstract #3673

Creep-induced atomic structural changes in hydrated tricalcium silicate and alkali-activated slag

Claire E. White, Abdelrahman Hamdan, Joseph Vocaturo, Brendan Kehoe, Princeton University, Princeton, NJ, Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL, Joerg C Neuefeind and S. Michelle Everett, Oak Ridge National Laboratory, Oak Ridge, TN, Daniel Olds, Brookhaven National Laboratory, Upton, NY and Katharine L. Page, Oak Ridge National Laboratory, Oak Ridge, and University of Tennessee, Knoxville, TN

Abstract Text:

Pair distribution function analysis (PDF) is well-suited for determining time-dependent local atomic structure changes occurring in amorphous and disordered systems. Sustainable cements, with reduced CO₂ emissions compared with Portland cement, fall into this category due to multiple amorphous phases that are known to evolve concurrently during initial formation and over the service life of the material. Viscoelastic relaxation of cement-based systems is known to control macroscopic creep, but the underlying mechanisms responsible for this viscoelastic behavior are still to be fully reconciled. Due to the high penetrating power of neutrons and their sensitivity to hydrated materials, neutron PDF analysis is

ideal for uncovering these mechanisms. However, typically PDF analysis assumes isotropic scattering which may not be applicable to cement systems subjected to uniaxial loads. Using a unique sample environment setup we have obtained directional-dependent neutron total scattering patterns and associated PDFs. Alkali-activated slag (AAS) and hydrated tricalcium silicate (hydrated C3S) cement cylinders have been subjected to 40% of their ultimate strength while data were collected in situ for the initial 24 hours, and then at 1, 2, 4, 8, 16 and ~32 weeks. Data analysis reveals that the atomic structural changes seen to occur over time are dependent on the loading direction, both in AAS and hydrated C3S. Potential mechanisms responsible for these changes are outlined.