The American Ceramic Society

2026 Cements Division
16th Advances in Cement-based Materials

Book of Abstracts

June 10-12, 2026
Coral Gables, FL

Keynote Speaker – Dr. Sriramya Nair

Wednesday, June 10, 2026, 8:45 – 9:30am

Cement Chemistry Under Extremes: Phase Evolution and Long-term Performance

Cementitious materials have long been used in subsurface environments such as oil and gas wells and are now also central to emerging geothermal applications, where extreme conditions drive significant chemical and microstructural change. Calcium (alumino) silicate hydrate (C-(A)-S-H), the principal binding phase in cementitious systems, is typically poorly ordered at ambient conditions, but transforms into mineral-like phases under subsurface high-pressure high-temperature (HPHT) conditions. Using a performance-based experimental framework, our work investigates how the starting oxide chemistry, aluminosilicate source, temperature, pressure, thermal cycling, age, and fluid acidity govern phase development and transformation. The first part of the talk shows how rigorous phase-identification approaches can establish links between early-age phase evolution and macroscopic material performance. The second demonstrates that, at critical transformation temperatures, long-term phase alterations of mineral-like hydration products are governed by the ionic medium and thermal cycling rather than by age alone. These results show that long term performance cannot be understood through equilibrium assumptions alone, but it must be interpreted through the kinetics and pathways of phase transformation in realistic cementitious systems.

Della Roy Lecture – Dr. Robert J. Flatt

Wednesday, June 10, 2026, 3:45 – 4:45pm

Lessons from Ceramics in Cement Research

Ceramics and cements share many common features. Both are prepared as suspensions mixing water and ground mineral powders. This leaves both domains with complex problems about the rheology of particulate suspensions, including questions of dispersion, particle shape and packing. Beyond this, they also share common questions about drying shrinkage and characterization of mechanical properties.

Such connections have been a source of inspiration for much of my research on cementitious materials. So, it seems very appropriate to discuss this connection between ceramics and cements for this Della Roy lecture at the Cements Division of The American Ceramic Society.

After trying to establish that panorama, I will develop some of cement-specific questions that are intimately tied to cement’s reactivity. They make these systems much more challenging to understand but also more exciting to study. While delving into those systems, it is to remember that in the “parent field” of ceramics, many lessons are learned by manipulating systems. How can this be done in cement? Which questions can we get enough grasp on in research and which topics should we better leave to industry? These are some of the questions that I hope to conclude the talk with.

Keynote Speaker – Dr. Evelien Martens

Thursday, June 11, 2026, 8:45 – 9:30am

Terra CO2 Technology: production of low carbon engineered cementitious materials through vitrification

Terra has developed a proprietary in-flight flash vitrification process to manufacture low-carbon SCM, called OPUS SCM^{TM}. For every ton of Portland cement replaced by OPUS SCM, a 70% reduction in CO_2 and 90% reduction in NOx emissions is achieved. Terra's technology is not restricted to narrow types of rock or mineralogy, which means the same reliable OPUS SCM can be produced from a variety of commonly available materials. Construction aggregate, which is already quarried in or near every large metropolitan area, is often suitable. In addition, waste materials such as mine tailings or under-performing natural pozzolans or fly ashes can be upgraded. Since 2022, Terra has been operating a 1 TPD facility in Golden, CO and has tested hundreds of samples from all over North America and beyond. Terra is currently building its first commercial plant in the Dallas-Fort Worth area in TX, which will be commissioned in 2027.

In the first part of this presentation, we will introduce our technology and products, share performance and durability data, and look at how Terra has scaled from lab scale to the first commercial plant.

Next, a case study will be presented, focusing on clays as feedstock for OPUS SCM and more specifically, comparing clay vitrification to clay calcination. In this study, different types of clays were both vitrified and calcined, and the products were tested in mortars and concrete, at different replacement levels. Pozzolanic reactivity, strength, and water demand will be discussed for both products.

Lastly, we will look to the future and Terra's path towards a true zero CO_2 cement; a complete Portland cement replacement.

A: Sustainability (Part 1 of 2)

Wednesday, June 10, 2026, 10:00am - 12:00pm

10:00am - Abstract #3846

Sodium carbonate looping for cost competitive cementitious materials

Kyle Shank; Lisa E. Burris; and Shang Zhai, The Ohio State University, Columbus, OH

Abstract Text:

We have developed a sodium carbonate looping process to accelerate CO_2 mineralization kinetics using steel slags by almost ten times compared to traditional pathways, achieving carbon storage capacities up to 2.79 mmol C g^{-1} slag. Our techno-economic analysis has indicated favorable economics, with estimated levelized CO_2 capture and mineralization costs of \$50 ton^{-1} for point-source capture and \$252 ton^{-1} for air capture. Including revenues, the process is projected to have payback periods under two years.

The process produces two solid products from silicate minerals or industrial wastes such as basic oxygen furnace (BOF) steel slag, electric arc furnace (EAF) steel slag, and fly ash: a carbonate-rich material composed primarily of calcium carbonate and an amorphous silica phase. In addition to permanently storing CO_2, the mineralization process eliminates expansive phases commonly present in steel slag while producing pozzolanically active silica, suggesting that the products may be suitable for use as supplementary cementitious materials (SCMs). SCM reactivity testing of carbonation products derived from BOF slag, EAF slag, and fly ash indicates moderate reactivity. Elemental analysis further shows low levels of alkali impurities in the carbonate-rich product, reducing potential concerns related to alkali–silica reactivity. Ongoing work focuses on hydration kinetics measurements and mechanical performance testing. This work aims to demonstrate a pathway for simultaneously utilizing industrial byproducts, permanently storing CO_2, and producing affordable low-carbon cementitious materials.

10:15am - Abstract #3710

Carbonate cement: A pathway to circular cement and CO2 supply chains

Richard E. Riman, Rutgers, The State University of New Jersey, Piscataway, NJ

Abstract Text:

The overall goal of my group's research has been to develop cement and concrete technologies that transform the concrete industry from the biggest CO_2 emitter to the largest CO_2 sink. Our research upcycles conventional concrete rubble using scalable mineral-processing methods, carbonation, and hydrothermal vapor synthesis (HVS) to produce fully recyclable, high-performance carbonate cement concrete. Our research began by studying carbonation curing with calcium-deficient cements to reduce the cement's carbon footprint and maximize the speed and extent of carbonation. Along this path, we identified simple low-cost carbonation methods that produced durable, strong materials with a form factor that could be demonstrated at production scales under mild reaction conditions of 25-90˚C and 2-6 atm. Following that work, we focused on finding conditions for reversing the carbonation reaction. We discovered and patented the use of unsaturated steam to produce both calcium-deficient and calcium-rich cements using temperatures ranging from 300-500˚C, and steam pressures on the order of 50 atm for decarbonation. This low-temperature cycle was repeated 5 times to demonstrate recyclability. Each time the cement was carbonated, a material displayed compressive strengths (>120 MPa), which is ~2 times higher than those achievable with Portland cement. Research is now underway to explore the use of CSH, HVS'd CSH, and recycled products to create carbonate cement products. In addition, we are examining the use of these materials for capturing, storing, transporting, and dispensing CO_2. Being able to do this will ensure a circular supply chain of CO_2 and cement. In addition, the availability of our recycling technology will lead to the launch of thousands of businesses that support the recycling of both

cement and CO_2. Being able to do this comes with a myriad of challenges, some of which will be discussed.

10:30am - Abstract #3863

Theoretical whole-life CO_2 emissions of concrete mixtures considering maximum CO_2 sequestration via carbonation

Matt A. Jungclaus; Sarah L. Williams; Jay H. Arehart; and **Wil V. Srubar III**, University of Colorado Boulder, Boulder, CO

Abstract Text:

A comparison of upfront embodied carbon emissions and carbon dioxide (CO_2) sequestration potential due to carbonation of portland cement (PC), portland limestone cement (PLC), and limestone calcined clay cement (LC3) concrete mixtures is presented in this work. First, the upfront embodied carbon emissions of the concrete mixtures were calculated using life cycle assessment (LCA). Then, the CO_2 sequestration potential of each mixture was computed using a theoretical model for CO_2 sequestration that was derived using principles of cement chemistry to account for the carbonation of both calcium hydroxide (CH) and calcium silicate hydrate (C-S-H). The results indicate that a theoretical maximum of 32% of the upfront embodied carbon emissions of the concrete mixtures analyzed herein can be realistically sequestered *via* carbonation. Data also substantiate that concrete mixtures with higher upfront embodied carbon emissions sequester the most CO_2. However, concrete mixtures with lower upfront embodied carbon emissions, namely PLC and Type I-V mixtures with high-SCM replacements, typically yield the lowest whole-life carbon emissions. The results indicate that concrete mixtures with high SCM replacement should be prioritized from a whole-life carbon emissions perspective (1) regardless of which cement is used to produce the concrete and (2) regardless of the amount of CO_2 sequestered via carbonation during (and after) its service life.

10:45am - Abstract #3899

Effect of kaolinite and illite on the performance of carbonation cementitious system

Md Montaseer Meraz; Pavan Akula; Chven Mitchell; and Jessica M. Rimsza, Oregon State University, Corvallis, OR; Sandia National Laboratories, Albuquerque, NM

Abstract Text:

Naturally abundant soil could be a lucrative supplementary material in the construction industry with its wide availability and potential for carbon embodiment. Currently there is a lack of comprehensive mechanistic evaluation of the use of such soils in cementitious systems. Therefore, this study investigates the mechanical and carbonation potential of soils that contain clay such as the minerals kaolinite and illite in a cementitious system. Simulant soils, composed of kaolinite and illite, were utilized as fine aggregate to substitute up to 50% of the sand in the base mix. The mechanical performance, shrinkage behavior, and durability under both normal and accelerated car bon curing conditions were evaluated. Early age performance indicates that accelerated curing (AC) enhanced the compressive strength up to 20% compared to normal curing (NC). At 28 days, the samples with kaolinite exhibited a notable strength drop of up to 22%, while the samples containing illite had a minimal strength reduction of up to 7%. Similarly, after 12 cycles of wetting and drying, the samples with illite retained 95% of their initial strength. The total shrinkage of kaolinite containing samples reached 18%, whereas the illite samples demonstrated less overall shrinkage of 8%, indicating a reduced susceptibility to volumetric deformation. These results provide insight into the feasibility of incorporating soil materials in construction and indicate that illite containing materials may be more suitable to for maintaining the mechanical integrity of structures with its minimal strength reduction and shrinkage.

11:00am - Abstract #3779

Structure-property interactions in biochar-amended recycled aggregate concrete

Fatemeh Hamidi; Victor Okumko; Andrew King; and Lori Tunstall, Civil, Colorado School of Mines, Golden, CO; Synchrotron SOLEIL, Saint-Aubin, France; PSL University, Evry, France

Abstract Text:

The rapid growth of construction and demolition waste (CDW) and the increasing depletion of natural aggregate resources have intensified interest in recycled concrete aggregates (RCAs) for structural applications. However, recycled aggregate concrete (RAC) typically exhibits reduced mechanical performance due to the presence of porous adhered mortar and weak interfacial transition zones (ITZs). This study proposes the incorporation of biochar as a sustainable strategy to simultaneously enhance RAC performance and promote carbon sequestration. Biochar was introduced at 15 wt.% of cement through partial replacement of fine aggregate to maintain a constant water-to-cement ratio. RCA replacement levels of 66% and 100% were evaluated using a strength-based mix design approach. Fresh-state properties and mechanical performance were systematically assessed to investigate the interaction between biochar and RCAs. Advanced multi-scale characterization techniques, including scanning electron microscopy (SEM), X-ray computed tomography (X-ray CT), and X-ray diffraction (XRD) were employed to elucidate microstructural evolution and ITZ modification mechanisms. The results demonstrate that optimized biochar dispersion mitigates the intrinsic weaknesses of RAC through filler effects, internal curing, and matrix densification, leading to compressive strengths comparable to or exceeding conventional concrete. This study provides mechanistic insight into microstructure-mechanical property coupling in biochar-amended RAC and supports its potential as a high-performance, low-carbon solution aligned with circular economy principles.

11:15am - Abstract #3704

Electrochemical production of next-generation, clean cement

Iman Mehdipour, Sublime Systems, Somerville, MA

Abstract Text:

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 NOx, SOx, 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 builds its first demonstration-scale plant. 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.

11:30am - Abstract #4007

How does the reactive transport of Mg^{2+} ions influence the phase composition of novel MgO-based cements?

Juan Pablo Gevaudan, Pennsylvania State University, University Park, PA

Abstract Text:

The current imperative to decarbonize the concrete sector has motivated the development of novel alternative cements. Of these alternatives, MgO-based cements have gained global attention due to their carbon-negativity global warming potentials stemming from innovative, electrified, and low-temperature manufacturing. However, the mechanisms of MgO hydration, in particular the reactive transport of Mg^{2+} ions is not well understood and limits the formulation design of durable MgO-based cements. In this presentation, I present the results of state-of-the-art review and thermodynamic simulations elucidating the mobility and transport of Mg^{2+} ions, particularly in promising MgO-silicate cements. While the structure of the MgO is important to contextualize the release and subsequent transport of Mg^{2+}, the mobility of ionic constituents is kinetically hindered due to the strong water-shell of Mg^{2+} ions which retards the mobility of these ions; and, the low solubility of $Mg(OH)_2$ phases. The latter presents a key issue as it forms as passive layers on reactive MgO interfaces resulting in a decreased release of Mg^{2+} and formation of cementitious phases. While these results are discussed in the context of modern non-classical formation pathways, thermodynamic simulations provide further evidence of the effect of chemical additives, namely citrate, carbonate, and orthosilicic acids, to increase the solubility of $Mg(OH)_2$ at higher pH levels relevant to cement formation. The findings here provide new insights to the engineering control and tunability of MgO-based microstructures to improve the durability of this promising type of carbon-negative cements.

11:45am - Abstract #4000

Utilizing the carbonated recycled cement powder for supplementary cementitious material

Aron Berhanu Degefa; Ji-Hyun Kim; and **Chul-Woo Chung**, Pukyong National University, Busan, South Korea

Abstract Text:

Recycled cement powder (RCP) is a waste material generated by the recycled aggregate industry. Owing to its high calcium content, it exhibits significant potential for mineral carbonation. Following carbonation, the chemical stability of silicate minerals in RCP is expected to decrease due to calcium leaching from the silicate structure. This suggests that carbonated RCP can be utilized as a supplementary cementitious material (SCM) to reduce the carbon footprint of construction materials. A modified R3 test is performed to evaluate the pozzolanic activity of carbonated RCP. X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FT-IR) are conducted to characterize the mineralogical changes in the cement paste. In addition, isothermal calorimetry, pore size distribution, and compressive strength tests are carried out to assess its influence on hydration behavior, pore refinement, and strength development. Thermodynamic modeling results are also discussed to further demonstrate its potential applicability.

B: AI and Modeling Techniques

Wednesday, June 10, 2026, 10:00am - 12:00pm

10:00am - Abstract #3939

Chemistry-informed machine learning for performance prediction and design space exploration of alkali-activated slag

Qiyao He; Zhanzhao Li; and Kai Gong, Rice University, Houston, TX

Abstract Text:

Understanding structure–processing–property relationships in alkali-activated materials is critical for their rational design and optimization. In this study, we present a chemistry-informed, data-driven framework for performance prediction and design space exploration in alkali-activated slag (AAS) systems across chemically diverse slag sources. A large literature-curated database was assembled, comprising more than 3000 data points from ~130 independent studies and ~150 distinct ground granulated blast-furnace slags. The database integrates mix design variables, precursor chemical and physical attributes, curing conditions, and specimen geometry within a unified feature space. A key component of this framework is the incorporation of a physically grounded reactivity descriptor, the average metal-oxygen dissociation energy (AMODE), to capture intrinsic slag reactivity. Multiple machine learning (ML) models (e.g., Gaussian Process Regression, Artificial Neural Network, Random Forest, and Extreme Gradient Boosting) were systematically benchmarked for strength prediction, and model-agnostic interpretation methods were applied to quantify feature influence and interaction effects. Results show that nonlinear ML models substantially outperform linear regression and identify precursor reactivity, activator chemistry (Na_2O dosage and silicate modulus), curing age, and water/slag ratio as dominant controls on AAS strength development. Surrogate-based design space exploration further reveals that optimal mix design depends strongly on intrinsic slag reactivity, with optimal activator dosage, silicate modulus, and water/slag ratio shifting systematically with AMODE. Integration of CO_2 emissions and material costs highlights coupled performance–sustainability–economy trade-offs. These results demonstrate how reactivity-informed ML can enable source-aware design optimization of AAS mixtures.

10:15am - Abstract #3855

Silica surface stability in high pH solutions

Jessica M Rimsza, Sandia National Laboratories, Albuquerque, NM

Abstract Text:

Adsorption of cations on silica surfaces is highly pH dependent, altering the charge density and stability of sorbed species. For silica, with random and varying silanol concentration, exposure of the surface to high pH conditions are known to alter the ability to form mineral assemblages during dehydration, with impact on the fundamentals of interparticle cohesion. Here, the stability of silica surfaces in contact with varying high pH aqueous solutions, including those containing sodium, potassium and calcium that are present in cementitious materials, are evaluated through reactive classical molecular dynamics simulations. The dynamic interactions of water, hydroxide ions, and varying cations are evaluated, including charge partitioning between the bulk water and surface regions, sorption sites and resonance times, and implications for interparticle cohesion. The results are compared with previous studies of sodium hydroxide and sodium chloride solutions, to identify specific features of sorption structures that influence the interfacial properties of silica in a variety of high pH environments. *SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525*

10:30am - Abstract #4002

Source-specific reactivity windows for calcined kaolinitic clays identified via Self-Validated Ensemble Models

Amir Hajibabaee and Grant McKnight, Ozinga Bros

Abstract Text:

Calcined clays are increasingly used as supplementary cementitious materials (SCMs), yet predicting their reactivity remains challenging because performance depends on both feed mineralogy and calcination conditions, and laboratory datasets are typically small and source specific. In this work, Self-Validating Ensemble Models (SVEM) were implemented via the SVEMnet R package to model a comprehensive laboratory dataset comprising five kaolinitic clay sources and 64 measurements spanning calcination temperatures of 600 to 800 °C and residence times of 30 to 90 min. Measured responses include R3 reactivity (isothermal calorimetry heat release) at 1 to 3 days, amorphous content, degree of dehydroxylation, and bound water. Two complementary targets were evaluated: (i) absolute properties across sources and (ii) within-source delta responses relative to a low-severity baseline to reduce cross-source shift. Using grouped-cell cross-validation (source by temperature by time), parsimonious absolute models using only calcination temperature, calcination time, and raw kaolinite content achieved $R^2 = 0.907$ to 0.913 for R3 reactivity (RMSE 38.07 to 44.76 J/g), $R^2 = 0.947$ for amorphous content (RMSE 3.81 wt%), and $R^2 = 0.870$ for mean bound water (RMSE 0.97 wt%). Delta models using calcination temperature and time, raw kaolinite, and baseline and delta dehydroxylation achieved $R^2 = 0.737$ to 0.786 for ΔR3 reactivity (RMSE 27.44 to 35.76 J/g) and $R^2 = 0.990$ for Δamorphous content (RMSE 1.14 wt%), while Δmean bound water remained less predictable ($R^2 = 0.600$). Beyond prediction, we introduce source-specific reactivity window and quality offset analyses that provide mechanistic interpretation by identifying diminishing-returns plateaus in activation state space and quantifying systematic source effects consistent with differences in amorphous quality. Overall, the results demonstrate that SVEM offers a transparent, small-data-appropriate framework for predicting and interpreting calcined clay activation while supporting anonymized workflows.

10:45am - Abstract #3908

Let’s accelerate & automate

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

Abstract Text:

Traditional testing for cement-based materials has been historically time and labor-intensive. Recent advances in imaging, low-cost sensors, and AI can accelerate and automate several of these traditional tests. In this talk, I will give an update on our recent efforts across 4 unique areas.

The 1st area is the particle scale analysis of concrete ingredients via Raman imaging. By quantitatively measuring the size and shape of individual mineral polymorphs in blended powders, we can now predict long-term performance within a few hours. The 2nd area is that of reactivity testing of Supplementary Cementitious Materials (SCMs), where we’ve introduced a new ‘Ultra-Rapid Reactivity’ (UR^2) test that can predict the 28-day Strength Activity Index (SAI) results in a matter of 5 minutes. The 3rd area is that of concrete durability, where we’ve introduced a low-cost computer vision approach that helps visualize water transport in real-time and can fully automate sorptivity measurements. Finally, the 4th area is that of AI-driven concrete mix design and optimization where we are using open-source algorithms to forecast strength of concrete to be deployed in datacenters.

11:00am - Abstract #3813

Rethinking crystallinity at the nanoscale

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

Abstract Text:

Salt crystallization plays a central role in the degradation of porous construction materials and is a major driver of damage in concrete exposed to saline environments. Understanding how salt crystals nucleate and grow is therefore important for improving concrete durability, but many of the relevant processes occur at length and time scales accessible only through molecular simulations. A central challenge in these simulations is to distinguish reliably between liquid-like and solid-like ions, especially at the nanoscale, where crystals are structurally fuzzy, yet key mechanistic events such as nucleation occur precisely in this regime. Conventional order parameters are often too conservative, identifying only highly crystalline ions and therefore missing much of the imperfect surface texture that defines nanoscopic crystals. Here, we introduce an order parameter based on network centrality, which classifies ions through their topological environment rather than local structural regularity alone. We show that this criterion more effectively distinguishes liquid and solid ions and better resolves the interfacial texture of nanoscopic crystals than conventional structural metrics. Our method provides a sharper lens to probe nucleation and early crystal growth in molecular simulations of salt crystallization.

11:15am - Abstract #3870

Structural descriptors linking atomic structure to macroscopic behavior in cementitious materials

Kai Gong; Weiqiang Chen; Qiyao He; Zhu Pan; and Zhanzhao Li, Rice University, Houston, TX; Hebei University of Technology, Tianjin, China

Abstract Text:

Establishing quantitative links between atomic-scale structure and macroscopic material behavior remains a major challenge in cement science, particularly due to the disordered and heterogeneous nature of many cementitious components. Here, we highlight recent developments in structural descriptors designed to bridge chemistry, atomic structure, and engineering-scale properties in cementitious systems.

We first introduce the average metal–oxygen dissociation energy (AMODE) parameter, originally developed to capture the intrinsic reactivity of synthetic calcium/magnesium–aluminosilicate glasses relevant to slag and fly ash. The framework was subsequently extended to more compositionally complex volcanic glasses and later simplified into a modified AMODE formulation that depends only on glass composition. Recently, we extended it to realistic alkali-activated material precursors containing mixed glass–crystalline phases. In separate efforts, we incorporated modified AMODE as an engineered feature in machine learning models to improve the prediction of mechanical performance and enable reactivity-informed exploration of composition–structure–property relationships in alkali-activated and blended cement systems. More recently, we developed related structural descriptor concepts for amorphous aqueous solutions to quantify local coordination environments controlling ion transport in cementitious nanopores.

Together, these studies demonstrate how structural descriptors provide a general framework for linking atomic structure to macroscopic behavior and guiding the design of next-generation cementitious materials.

11:30am - Abstract #3852

Multiscale insights into graphene oxide interactions in cementitious materials using molecular dynamics simulations

Meili Liu and Xianming Shi, University of Miami, Coral Gables, FL

Abstract Text:

Graphene oxide (GO) has attracted increasing attention as a nanomaterial for enhancing the performance and sustainability of cementitious materials due to its high specific surface area and abundant oxygen-containing functional groups. Experimental studies have demonstrated that GO can influence cement hydration, refine microstructure, and improve the mechanical performance of cement-based systems. However, the molecular-level mechanisms governing the interactions between GO and cement hydration products remain poorly understood. In this work, molecular dynamics (MD) simulations are employed to investigate the interfacial interactions between GO and key hydration phases, particularly calcium-silicate-hydrate (C-S-H). The simulations focus on understanding adsorption behavior, interfacial bonding, and structural evolution at the GO-C-S-H interface. By integrating experimental observations with atomistic modeling, this study provides multiscale insights into how GO modifies hydration processes and microstructure development in cementitious materials. The modeling results help bridge atomistic interactions with macroscopic material behavior and demonstrate the potential of molecular simulations as a powerful tool for guiding the design of advanced and sustainable cement-based materials.

11:45am - Abstract #4003

Towards a more general simulation framework for microstructure development in cementitious binders

Jeffrey W. Bullard and Florin Nita, Texas A&M University, College Station, TX

Abstract Text:

Both cement pastes and natural sedimentary deposits share the characteristic that their phase assemblages and microstructural characteristics change over time as a function of their chemical, thermal, and mechanical environments. Such changes generally influence the medium's chemical and physical properties, and one often wants to predict how (and how fast) those properties will change with time. This presentation will describe a 3D model of porous, multiphase microstructure that is linked to general kinetic and geochemical speciation models to simulate the detailed phase evolution and structural changes for diverse natural and industrial processes. The model accommodates a wide range of phase assemblages and environmental conditions based on user input. Examples will be shown for hydration of different cement pastes, carbonation of slaked lime, and oxidation of pyrrhotite. In addition, several important properties of the material can be computed from finite element calculations directly on the 3D microstructure representation, including linear elastic moduli and transport properties.

C: Concrete Durability

Wednesday, June 10, 2026, 1:15pm - 3:15pm

1:15pm - Abstract #3770

Role of carbon nanotubes on alkali-silica reaction

Hwan Lee; Aniruddha Baral; and Raissa Ferron, University of Texas at Austin, Austin, TX; University of Illinois Urbana-Champaign, Urbana, IL

Abstract Text:

This study investigated the effectiveness of Carbon nanotubes (CNTs) at low dosages (up to 0.05% by weight of cement) in mitigating alkali-silica reaction (ASR) expansion. Using accelerated mortar-bar tests with highly reactive aggregates, results showed that while a 0.01% dosage was insufficient, 0.05% CNTs significantly reduced expansion by 67.7%. This mitigation is attributed to a synergy of physical and chemical mechanisms. Physically, mercury intrusion porosimetry confirmed that CNTs densified the matrix and refined the pore structure, thereby limiting ion transport. Chemically, microstructural analysis revealed that CNTs modified the ASR gel composition, significantly lowering its Na/Si ratio from 0.604 to 0.278, which reduced the gel's osmotic swelling potential. These findings demonstrate that CNTs can effectively mitigate ASR through both physical confinement and chemical alteration of the reaction products.

1:30pm – Abstract 3966

Carbonation-induced physicochemical transformations and moisture absorption changes in alkali–silica reaction gels

Jianqiang Wei and Arkabrata Sinha, University of Maryland College Park, College Park, MD; University of Florida, Gainesville, FL

Abstract Text:

The formation and hydroscopic swelling of alkali–silica reaction (ASR) gels are a major cause of volume expansion, cracking, and deterioration in concrete containing reactive aggregates. Once cracking occurs, the ingress of external moisture and CO_2 can induce carbonation of these highly alkaline calcium-silicate reaction products, altering their composition, structure, and deleterious behavior. This study investigates the carbonation kinetics of ASR gels and the resulting changes in crystallinity, mineral phases, molecular structure, and moisture absorption behavior. The results indicated positive correlations between the extent and rate of carbonation and CO_2 concentration, temperature, and Ca/Si ratio, resulting in a substantial reduction in the amorphous character of ASR gels and promoting the conversion of tobermorite-type calcium silicate hydrate (C-S-H) and alkali silica hydrate (ASH) into carbonate phases, including nahcolite, calcite, and vaterite. As a result, the moisture absorption capacity of ASR gels was decreased. These findings show that carbonation can trigger significant modifications in the composition and properties of ASR gels and suppress their deleteriousness, providing new insight into ASR evolution under realistic environmental conditions.

1:45pm - Abstract #3933

Design of freeze-thaw resistant limestone-calcined clay based cementitious materials

Ahmed Salah Jamal and Mehdi Khanzadeh Moradllo, Temple University, Philadelphia, PA

Abstract Text:

Concrete industry is experiencing significant uncertainty in the availability and quality of frequently used SCMs such as fly ash and slag. Calcined clays and ground limestone with abundant sources worldwide have tremendous potential to be implemented as partial replacements of clinker in cement and concrete. When combined with clinker, they form limestone calcined clay cement (LC3), a ternary binder capable of reducing CO_2 emissions by about 30–40% compared with OPC while maintaining comparable mechanical and durability performance to OPC systems. Although previous studies have demonstrated promising durability characteristics of LC3, limited information is available regarding its freeze–thaw design and durability, particularly for air-entrained systems. Freeze-thaw causes billions of dollars of damage to concrete infrastructure and buildings in the US yearly. This study investigates the air-entrainment behavior of several AEAs in both LC3 and OPC mixtures, considering the influence of superplasticizer and different water–cement ratios. Surface tension and foam index tests were first conducted to evaluate the performance of different AEA types. Fresh air content of the mixtures using different AEAs was then measured . Finally, the air-void system of hardened specimens was characterized through optical microscopy and image analysis for samples with different air contents. This study also implemented thermomechanical analysis (TMA) to quantify the frost-induced damage in LC3 and OPC systems with micro-scale resolution. Additionally, water absorption and porosity measurements, along with microstructure characterization, were performed to relate the freeze-thaw performance to the microstructural and mass transport properties of LC3 systems. The results provide insight into the interaction between AEAs and LC3 systems and contribute to understanding the air-void structure required to support freeze–thaw durability in LC3 binder systems.

2:00pm - Abstract #3946

Evaluating structural anisotropy from neutron pair distribution function analysis of uniaxially-loaded sustainable cement undergoing viscoelastic relaxation

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

Abstract Text:

Aging of concrete structures is, in part, attributed to the viscoelastic deformation of cement paste, also known as creep. Under sustained service stresses, cement paste tends to deform, potentially due to changes to the atomic structure of the calcium-silicate-hydrate (C-S-H) gel as well as time-dependent macroscopic volumetric changes of concrete. However, despite significant progress, the phenomenon of creep in cement paste is still far from being fully understood, attributed to the lack of experimental data probing changes at the atomic and nanometer length scale during sustained compressive loading. As such, in situ neutron scattering pair distribution function (PDF) analysis is well-suited for providing these insights. In this research, a custom-built novel load frame was used as a neutron scattering sample environment, enabling time-dependent stress-induced changes to be studied under compression. Hydrated C_3S (using D_2O) and deuterated alkali-activated slag (AAS) paste specimens were placed in uniaxial compression and measured over a period of six months on the NOMAD instrument at the Spallation Neutron Source, Oak Ridge National Laboratory, obtaining in situ neutron PDF data. Direction- and time-dependent analysis of the measured reciprocal and real-space data was performed to infer creep behavior at the atomic length scale, revealing subtle changes in the total scattering data because of

the sustained loading. Preliminary analysis reveals that loading likely causes a reorientation of local atom-atom correlations, indicating reorganization of silica chains in the C-S-H gels due to particle reorientation and/or dissolution-precipitation of the gel phase.

2:15pm - Abstract #3992

Interaction between air entraining admixtures and ground glass pozzolan in freeze-thaw durability of low-carbon concrete

Subhashree Panda; Md Maruf Hasan; Matthew J. Bandelt; and Matthew P. Adams, New Jersey Institute of Technology, Newark, NJ

Abstract Text:

Ground-glass pozzolans (GGP) derived from soda-lime waste glass are an emerging supplementary cementitious material (SCM) that can partially replace clinker and reduce the carbon footprint of cementitious systems. Large quantities of post-consumer glass remain landfilled in the United States despite being silica-rich and highly amorphous, making it suitable for pozzolanic reactions when processed and finely ground. Converting this waste into GGP offers a pathway to improve recycling while addressing the growing scarcity of traditional SCMs. However, despite their promising sustainability benefits, the long-term durability performance of GGP-modified cementitious systems remains insufficiently understood. Our previous laboratory trials evaluated the freeze-thaw (F–T) performance of low-carbon concrete containing 30% GGP for 300 cycles in a controlled F–T chamber. Despite an initial air content of approximately 6%, all trials exhibited premature failure before reaching 200 cycles. These observations suggest that interactions between GGP surface characteristics, particle size, and air-entraining admixtures (AEA) may influence adsorption behavior, bubble formation, and the stability of the hardened air-void system. Therefore, this study aims to elucidate the mechanisms governing GGP–AEA interactions and their influence on freeze–thaw durability. Mixtures containing 0–35% GGP are evaluated through freeze–thaw cycling alongside microstructural and reaction analyses using X-ray diffraction (XRD), thermogravimetric analysis (TGA), Isothermal calorimetry (IC), and Brunauer–Emmett–Teller (BET) surface area measurements. The results aim to establish composition-reactivity-durability relationships that clarify the mechanisms controlling air-void stability and freeze-thaw resistance in GGP-modified systems and guide the design of durable low-carbon cementitious materials.

2:30pm - Abstract #3771

Using ground tire rubber as an air-entraining agent in concrete: Technical feasibility

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

Abstract Text:

This presentation discusses the performance of concrete mixtures with different sizes and different volume fractions of ground rubber particles. An increase in air content with an increase in rubber quantity, despite the absence of an AEA, was noted. This is attributed to the hydrophobic character of the rubber particles, attracting the air bubbles during the mixing process. As such, different strategies were employed to attempt to reduce this air content: defoaming agents, vibration and extended mixing time. The mechanical properties decreased with increasing rubber content, as expected, and relate well with the sum of the rubber and air contents. Concrete with ground tire rubber performs adequately in freeze-thaw tests, provided that the mixture contains sufficient rubber, that the rubber is not too fine, and that the mixture is not defoamed. Indeed, the freeze-thaw resistance in concrete with ground tire rubber is caused

by the air entrained by the rubber, and not the deformability of the rubber itself. Furthermore, leaching tests indicate no release of 6PPD-Q from the concrete to the environment. As such, as long as the air content can be guaranteed, the use of ground tire rubber in concrete is technically feasible.

2:45pm – Abstract # 3732

Artificial neural network based prediction of concrete strength from non-destructive testing under variable curing conditions

Ghazal Gholami Hossein Abadi, Texas State University, San Marcos, TX

Abstract Text:

Non-destructive testing (NDT) methods are widely used to evaluate the performance of concrete, but their accuracy can be influenced by external factors such as curing temperature. Temperature not only modifies hydration kinetics and strength development but may also change the correlation between NDT measurements and compressive strength. However, no prior research has systematically examined how different curing temperatures influence the reliability of various NDT techniques. This study evaluates three curing temperatures and their effect on the correlation between NDTs and compressive strength at various ages (1, 3, 7, 28, and 90 days). Both simple regression analysis and artificial neural networks (ANNs) were employed to predict strength from NDT measurements. Results show that NDT sensitivity to curing temperature is most pronounced at early ages, and that linear regression models cannot adequately capture the complexity of these relationships. In contrast, ANNs demonstrated superior predictive capability, though initial training with limited data led to overfitting and instability. By applying Gaussian Noise Augmentation (GNA), model accuracy and generalization improved substantially, achieving R2 values above 0.95 across training, validation, and test sets. These findings highlight the potential of non-linear models, supported by data augmentation, to improve prediction reliability, lower experimental costs, and more accurately capture the role of curing temperature in NDT–strength correlations for concrete.

3:00pm - Abstract #3953

Raman imaging for mineralogical characterization of concrete aggregates: Implications on ASR susceptibility

Omar F Durrani, University of Illinois, Urbana Champaign, Champaign, IL

Abstract Text:

Accurate characterization of aggregate mineralogy is essential for understanding the performance and durability of concrete materials, yet conventional techniques such as petrographic analysis and bulk X-ray diffraction (XRD) are often labor-intensive, costly, and limited in their ability to resolve spatial heterogeneity and mineral polymorphs within individual aggregate particles. Here we investigate Raman imaging using large-area spectral mapping to determine the mineralogical composition of aggregates. We find that Raman imaging can resolve major minerals, including quartz, feldspars, amphiboles, pyroxenes, epidote-group minerals, and TiO_2 polymorphs. These results demonstrate the potential of Raman spectroscopic mapping as a scalable tool for aggregate mineralogical characterization and is being explored for an ongoing study of investigating long term aggregate reactivity and susceptibility for ASR.

D: Cement Chemistry

Wednesday, June 10, 2026, 1:15pm - 3:15pm

1:15pm - Abstract #3993

Selective nano-seeding of cement phases using CaAl-NO_3 layered double hydroxide

Godwin Ogbuehi and Monday U. Okoronkwo, Missouri University of Science and Technology, Rolla, MO

Abstract Text:

Layered double hydroxides (LDHs) are emerging as multifunctional additives in cementitious systems, yet their phase-specific mechanistic role remains unclear. This study investigates CaAl-NO_3 LDH (CAN) as a hydration-active nanoseed in phase-pure tricalcium silicate (C_3S) and ye'elimite–gypsum (YG) systems to isolate its influence on hydration kinetics and product evolution. Isothermal calorimetry shows that CAN accelerates early hydration in both systems, reducing induction time while maintaining controlled heat release. Time-resolved X-ray diffraction confirms that CAN enhances early formation of C–S–H in C_3S and ettringite in YG without altering intrinsic reaction pathways. Thermogravimetric analysis reveals increased bound water and shifts in phase assemblage, indicating selective redistribution of hydration products. Complementary electrokinetic, BET surface area, and SEM analyses suggest that CAN modifies interfacial conditions and provides nucleation sites, promoting denser early-age microstructures. These results demonstrate that CAN functions as an active nanoseed that selectively regulates hydration kinetics and phase partitioning rather than changing reaction chemistry. The mechanistic insights support the design of LDH-based additives for controlled early-age performance and advanced cementitious materials.

1:30pm - Abstract #3854

In-situ raman imaging of early stage carbonated cement hydration

Marcin Hajduczek; Santiago El Awad; Yogiraj Sargam; Sean Monkman; Vishnu Chaudhari; Admir Masic; and Franz Josef Ulm, Massachusetts Institute of Technology, Cambridge, MA; Indian Institute of Technology Jodhpur, Jodhpur, India; CarbonCure Technologies, Dartmouth, Canada

Abstract Text:

To investigate the complex reaction mechanisms governing CO_2 mineralization in cementitious systems, a customized Raman spectroscopy setup was developed to perform in-situ and operando imaging of early-stage hydration. By employing spatial mapping and autocorrelation function analysis over the first 24 hours of hydration, a fundamental mechanistic baseline was established using direct, low-dose gaseous CO_2 injection (1% by weight). The results show that CO_2 mineralization accelerates the dissolution of clinker phases, leading to the formation of multiple calcium carbonate polymorphs alongside a transient amorphous silica gel network. Once the available CO_2 is consumed, conventional hydration resumes, resulting in the delayed formation of C-S-H and portlandite. A distinct secondary C-S-H phase (C-S-H*) was also observed, likely originating from a localized pozzolanic reaction at the silica gel-portlandite interface. This foundational understanding of carbonation-hydration pathways was leveraged to propose a novel framework to store high doses of CO_2 in cementitious materials (10-15% by weight). This was achieved through chemically induced pre-cure carbonation, whereby carbon is introduced to a concrete mix in the form of a solid, mix-friendly powder, rather than a gas. Correlated chemo-mechanical analysis across the early stages of hydration demonstrates that these formulations achieve controlled, scalable CO_2 storage. Crucially, by identifying rapid aluminate hydration as a primary driver of flash setting in carbonated systems, targeted chemical retardation was introduced to stabilize the binder kinetics. Through such mix optimization, chemically induced pre-cure carbonation was shown to offset up to 40% of calcination emissions without compromising structural integrity. By tracking mineral phase

transformations across varying CO_2 dosages, this work provides new insights for the intentional engineering of high-capacity carbon-mineralized cementitious systems.

1:45pm - Abstract #3730

Surface interfacial dissolution phenomena of calcium silicates

Aidyn Tugelbayev; Hongyu Wang; D. Jarret Wright; Jing Zhao; F. Marc Michel; and Alexander S. Brand, Virginia Tech, Blacksburg, VA

Abstract Text:

Tricalcium silicate (Ca_3SiO_5) and dicalcium silicate (Ca_2SiO_4) are the main components of cement clinker, which control cements' hydration kinetics and strength development. Although their long-term macroscopic properties and hydration behavior are well reported in the literature, the processes occurring during the initial contact with water, when the reaction rate temporarily decelerates, remain poorly understood.

Geochemical studies of natural silicates suggest that this reduced dissolution rate may arise from the formation of altered surface silica-rich layers (ASSLs), produced *via* coupled interfacial dissolution-reprecipitation (CIDR) of amorphous silica from the parent mineral. In this work, the dissolution of tricalcium and dicalcium silicate in water was assessed with respect to CIDR mechanism. The morphology and passivating behavior of ASSLs were investigated using transmission electron microscopy (TEM), and the surface density and roughness changes were analyzed using X-ray reflectivity (XRR).

TEM results show that ASSL morphology and passivation correlate with the crystallographic orientation, with Si-rich faces forming dense, passivating layers, while Ca-rich faces remain more reactive and form porous silica networks. XRR results have demonstrated that the surface of calcium silicates develops a change in the top surface density, which could also potentially indicate the reprecipitation mechanism. These findings support the ASSL formation in calcium silicates *via* CIDR as a key mechanism governing early-stage dissolution of calcium silicate phases in cement, rather than the classical leached-layer model.

2:00pm - Abstract #4001

Programming earthen materials' shape retention with synergistic biopolymers for 3D printing

Yierfan Maierdan; Akul N. Seshadri; Yohan Jacquet; Sabrina Fazio DeAraujo; Kendra A. Erk; and Shiho Kawashima, Columbia University, New York City, NY; Purdue University, West Lafayette, IN; Technical University of Denmark, Lyngby Denmark

Abstract Text:

Additive manufacturing of bio-stabilized earthen materials offers a low-carbon, waste-free path to sustainable construction. Although various biopolymer additives have been used to improve printability, their ability to deliver cohesion, high mechanical strength, and shape retention in a unified formulation remains limited. We report a synergistic combination of biopolymers—xanthan gum (XG) and locust bean gum (LBG)—that meets all these requirements. XG and LBG form a reversible supramolecular gel network that couples strong mineral surface binding with enhanced internal structuration. Compared to single-polymer systems, XG–LBG mixtures exhibit four- to tenfold increases in yield stress, an order-of-magnitude higher storage modulus, and markedly improved thixotropic breakdown and recovery—key properties for extrusion-based additive manufacturing. To uncover the underlying interaction mechanisms, we develop an experimental workflow that integrates polymer rheology, sequential physicochemical characterization, and suspension rheology. This approach enables us to decouple the roles of polymer–

polymer, polymer–clay, and clay–clay interactions. Based on these findings, we identify two critical characteristics of polymer-based rheology modifiers that improve buildability in 3D-printed earthen materials: a strong binding affinity to mineral surfaces and sufficient intrinsic gelation to maintain structural integrity during and after extrusion.

2:15pm - Abstract #3787

Linking composition to mechanical performance and transport properties of type IL cement

Zeyu Wang; Devon Golden; Collins Twum; Newell R Washburn; and Kimberly E. Kurtis, Georgia Tech, Atlanta, GA; 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 varying limestone contents, and their impact on mechanical performance, remains a critical research challenge. Here, 63 Type IL cement samples were sourced from 17 different manufacturers across the U.S., including cements from 24 states.

Chemical quantitative analysis was carried out, utilizing in-situ XRD, XRF, TGA, and SEM with EDS. Physical properties, including specific gravity and particle size distribution, are obtained by three methods: Blaine, 45μm-sieve residue, and laser particle size analysis. Performance tests were performed on pastes and mortars, including isothermal calorimetry (up to the first 72h), initial and final setting time, mortar flow, air content, and cube strength (1, 3, 7, 28, 90days). A bulk resistivity test on 2x2-inch mortar cubes was conducted every day for the first week and every week after until 90 days, comparing the resistivity development of Type IL portland cement with other types of cement, including Type I/II, Type III, Type IS, Type IP, and LC3. The results show that the resistivity of different Type IL portland cement increases differently over time and differs from the growth in compressive strength. Therefore, a series of interpretable machine learning predictive models and thermodynamic models are being developed to establish relationships between chemical compositions and physical properties with the mortar mechanical performance and transport properties.

2:30pm - Abstract #3956

Crystal vision: An interactive computer video game for learning basic crystallography

Nanzeeba Tabassum; Jacob Henschen; Jenny Amos; Eric Shaffer; and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

Educational games have increasingly advanced STEM learning by improving immersion and engagement over the last few decades. Materials crystallography is a fundamental concept towards the design of innovative construction materials. However, its atomic-scale visualization and abstract reasoning impose a high cognitive burden, often leading to student disengagement. Although game-based learning has been adopted across numerous STEM disciplines, narrative video games tailored to teach crystallography remain largely unexplored. Here we show that a computer-based educational game, Crystal Vision, can improve learning complex crystallography topics through 3D atomic structure visualization and interactive narrative exploration. Implemented with 82 undergraduate students, the intervention yielded an 18.9% increase in post-test performance relative to pre-test scores, as measured by a structured learning-gain metric, while 48.6% of participants self-reported meaningful learning benefits. The findings suggest that integrating scaffolded gameplay with crystallographic concepts

transforms cognitively demanding content into story-based challenges that promote intrinsic motivation and sustained conceptual engagement.

2:45pm - Abstract #3994

Revisiting hydrogrossular: Experimental evidence against a miscibility gap

Aniruddha Baral; Boyang Zhan; and Theodore Haneina, University of Leeds, Leeds, United Kingdom; University of California, Los Angeles, CA; University of Texas at Austin, Austin, TX

Abstract Text:

Hydrogrossular is a common mineral present in cement hydrates and earth's hydrosphere. It is the solid solution between Katoite ($Ca_3Al_2(OH)_{12}$) and Grossular ($Ca_3Al_2(SiO_4)_3$) and generally observed in cements cured at high temperature. However, hydrogrossular formation kinetics and existence of a miscibility gap in hydrogrossular, often reported in literature, is not well-understood. In this work, we hydrothermally synthesized hydrogrossular under different Si concentrations, temperatures and durations. We were able to synthesize hydrogrossular with continuous chemical composition within the miscibility gap proposed in previous studies, directly disproving the existence of the miscibility gap in hydrogrossular. The coexistence of two types of hydrogrossular commonly observed, and often mistaken as miscibility gap, was found to be related to reaction kinetics, which favors formation of Si-poor hydrogrossular. A multi-step crystallization process of hydrogrossular formation is also proposed to explain the two types of hydrogrossular observed. Further, the Si-content in the Si-rich hydrogrossular increased with synthesis temperature, including iron-incorporated hydrogrossular. These findings advance the characterization of the hydrogrossular solid solution and would improve the thermodynamic simulation of cement hydration at high temperature.

3:00pm - Abstract #3964

How temperature sensitive are calcined clay-type IL cement blends?

Kyle Austin Riding; Sristi Das Gupta; Randa Zeidan; Christopher C. Ferraro; Kimberly E. Kurtis; Maria Juenger; and Kejin Wang, University of Florida, Gainesville, FL; Georgia Institute of Technology, Atlanta, GA, University of Texas at Austin, Austin, TX; Iowa State University, Ames, IA

Abstract Text:

Limestone-calcined clay cementitious systems are beginning to be used in concrete because of their ability to reduce environmental footprint while maintaining or improving strength and desired durability properties. One possible path to implement these systems is by blending calcined clay with ASTM C595 Type IL cement at the ready-mixed concrete plant. Cement hydration is a temperature sensitive reaction that is often characterized by the use of an apparent activation energy. The apparent activation energy of these calcined clay-Type IL (CC_IL) systems were calculated from isothermal calorimetry experiments performed at 15°C, 23°C, 30°C, 40°C, and 50°C. A statistical analysis was performed on the material composition and activation energies and found that the calcined clay SiO_2 and Al_2O_3 were significant parameters in determining the apparent activation energy.

E: Sustainability (Part 2 of 2)

Thursday, June 11, 2026, 10:00am – 12:00pm

10:00am - Abstract #3856

Sustainable alkaline binders using composite precursors of hardened recycled concrete and blast furnace slag

Efrain E. DLR-Garcia; J. Ivan Esacalante-Garcia; and O. Burciaga-Diaz, Cinvestav Saltillo, Saltillo, Mexico; Instituto Tecnologico de Saltillo, Saltillo, CU, Mexico

Abstract Text:

Portland cement production accounts ~8% of global anthropogenic CO_2 emissions, while concrete represents ~67% of the stream of 10 Gt/year of construction and demolition waste. These challenges motivate the development of alternative cementitious systems capable of valorizing industrial waste as resources.

This study investigates alkali-activated cements (ACC) based on limestone-aggregated based recycled concrete (RC) and blast furnace slag (BFS) as precursors. One-part and two-parts type cements were prepared by varying the modulus of the sodium silicate activator, curing conditions and RC content. The mechanical performance was evaluated through compressive strength testing, and the development of cementitious phases was analyzed by scanning electron microscopy, X-ray diffraction and Energy Dispersive Spectroscopy.

The results show that one-part cements exhibit hydraulic behavior and high mechanical performance, reaching strengths up to 41MPa at 28 days. The curing temperature significantly influences strength development. Cementitious formulations with higher RC contents require activators with lower modulus to promote mechanical performance.

The overall results highlight the viability of using RC as a less environmentally intense cementitious precursor in AAC, increasing its added value beyond its use as recycled aggregates. Moreover, as BFS is a very valuable supplementary cementitious precursor but of relatively limited availability, this study offers a route to extend the value and availability of BFS by replacing it with an environmental passive such as a RC, where these work in synergy to produce novel and competitive cements of low environmental impact.

10:15am - Abstract #3963

A pilot study of using recycled PET flakes as sustainable fine aggregates in concrete

Sailong Hou; Jialuo He; and Xianming Shi, Washington State University, Pullman, WA; Widener University, Chester, PA; University of Miami, Coral Gables, FL

Abstract Text:

The recycling of waste polyethylene terephthalate (PET) plastics into cement-based materials offers a promising pathway to reduce environmental impacts while valorizing plastic waste. This pilot study investigates the feasibility of incorporating recycled PET flakes as a partial replacement for natural fine aggregates in concrete and examines its influence on mechanical performance and fracture characteristics. Discarded PET flakes were mechanically processed into fine particles and introduced into concrete mixtures at different replacement ratios. Standard mechanical tests were conducted to evaluate compressive strength, while fracture surfaces of failed specimens were quantitatively characterized using surface roughness analysis to assess changes in fracture morphology. The results indicate that the incorporation of PET particles leads to a gradual reduction in compressive strength compared with the control mixture, which is primarily attributed to the weaker stiffness of plastic particles and reduced interfacial bonding with the cement matrix. However, fracture surface analysis reveals a consistent increase in fracture roughness with increasing PET content. The rougher fracture morphology suggests enhanced crack deflection and tortuous crack propagation paths introduced by the PET inclusions. These observations indicate that although PET incorporation reduces the overall load-bearing capacity, it significantly alters fracture behavior and failure morphology. The findings provide new insights into the role of recycled plastic particles in modifying fracture processes in cement-based materials and highlight the potential of PET aggregates for developing sustainable and damage-tolerant concrete composites.

10:30am - Abstract #3965

Mineralogical and performance evaluation of a volcanic natural pozzolan for use as a supplementary cementitious material

Moe Sharbaf; Rafic Minkara; and Christy Sieg, EP Power Minerals, Atlanta, GA

Abstract Text:

Natural pozzolans have received increasing attention as supplementary cementitious materials (SCMs), creating a need for more reliable approaches for evaluating their quality during source assessment. In practice, mineralogical indicators are often used as screening tools; however, their relationship to pozzolanic performance has not been adequately established. This study examined the relationship between semi-quantitative X-ray diffraction results and standardized reactivity metrics for a volcanic natural pozzolan. The mineralogical screening results were compared with ASTM C1897 R^3 paste heat release, bound water, modified heat release, and ASTM C618 strength activity index measurements. The results showed only weak correlations between the mineralogical indicator and the measured reactivity, indicating that such screening metrics should not be used as standalone indicators of SCM performance. Concrete mixtures containing the natural pozzolan at 20% cement replacement showed compressive strength comparable to mixtures prepared with Class F and Class C fly ashes, along with acceptable fresh and durability properties. Overall, the results indicate that volcanic natural pozzolans can provide suitable SCM performance when properly processed and evaluated, and they underscore the importance of performance-based testing in the assessment of new natural pozzolan sources.

10:45am - Abstract #3986

Aluminum availability and uptake into C–(A)–S–H from mixed-layer aluminosilicates: Mechanistic insights from the building materials research area at Chalmers

Arezou Babaahmadi, Chalmers University, Gothenburg, Sweden

Abstract Text:

Activation modifies short-range structure and the coordination of aluminum in mixed-layer and low-kaolinite clays, increasing their susceptibility to alkaline dissolution. During dissolution, these clays release Al with kinetics and amounts that differ from kaolinite-rich materials. Because mixed-layer and low-kaolinite clays also have lower bulk Al content, early-age Al availability in the pore solution is comparatively limited. Under these conditions, the balance between Al incorporation into C–(A)–S–H and the formation of separate aluminate-bearing hydrates depends on the solution composition and reaction progress.

In work carried out within the Building Materials Research Area at Chalmers, we observe that, for mixed-layer systems with comparatively low Al availability, the dissolved Al that is released during dissolution is predominantly taken up by C–(A)–S–H, and AFm-type phases remain minor or not detected even when carbonate is present. By contrast, for kaolinite-rich precursors where bulk Al content and dissolved Al availability are higher, AFm can form alongside C–(A)–S–H in the presence of excess calcite. These observations indicate that both intrinsic Al content and dissolution behavior are important in determining the resulting Al content and partitioning within the hydrate assemblage.

Our results also show that the pore solution environment plays a decisive role in determining how much Al enters C–(A)–S–H. Small shifts in Ca/Si, Al/Si, and early silicate concentration can influence whether

Al is retained within the C–(A)–S–H structure or diverted toward minor aluminate hydrates. These sensitivities suggest that Al uptake can be moderated by controlling Ca/Si ratios, increasing early silicate concentration, or adjusting ionic strength or alkalinity to alter Al speciation.

Finally, we observe that the extent of Al incorporation affects the longer-term behavior of the hydrate assemblage, including its response to decalcification and carbonation. This links early-stage Al availability and precipitation paths to later stability and performance.

By connecting these findings, this contribution clarifies the mechanistic factors that govern Al release from mixed-layer aluminosilicates, the pathways by which Al enters C–(A)–S–H, and the chemical conditions under which this uptake may be reduced. The aim is to provide a coherent basis for designing future experiments and for interpreting Al behavior in aluminosilicate-based cementitious systems.

11:00am - Abstract #3793

Re-establishing air entrainment in biochar-rich concrete through tailored biochar surface engineering

Mahdi Mirabrishami; S.H. Chu; and Farshad Rajabipour, Pennsylvania State University, State College, PA

Abstract Text:

Biochar has attracted increasing interest as a sustainable constituent in cementitious materials because its carbon sequestration potential offers a pathway to reduce the embodied carbon footprint of concrete. However, its incorporation into air-entrained concrete presents a significant challenge because the carbonaceous hydrophobic surface of biochar can strongly adsorb air-entraining admixtures (AEAs), reducing their availability in the pore solution and thereby destabilizing entrained air voids. This study investigates strategies aimed at modifying the surface characteristics of biochar to reduce its interaction with AEAs and restore stable air entrainment in cementitious mixtures.

Surface modification approaches, including surface saturation with sacrificial agents and surface oxidation, were applied to biochar particles, and their effectiveness was evaluated through adsorption measurements, surface characterization techniques, and air-entrainment performance tests. Experimental results demonstrate that untreated biochar significantly increases AEA demand and severely reduces the air content of mortar mixtures. In contrast, surface-saturated biochar particles exhibit substantially lower interaction with AEAs and allow the recovery of air entrainment levels comparable to conventional air-entrained mixtures. Surface analyses also indicate that altering the surface chemistry of biochar reduces its affinity for surfactant-based admixtures, thereby preserving the functionality of the air-entraining system.

The findings highlight the critical role of biochar surface properties in governing admixture compatibility and demonstrate that targeted surface modification can enable the use of biochar as a sustainable component in air-entrained concrete.

11:15am - Abstract #3918

A hybrid mechano-thermal synthesis route to activate clay minerals as scms: A case of kaolinite

Oluwadamilare Charles Adesina; Bryan K. Aylas-Paredes; Brian R. Cherry; Luciano A. Gobbo; Aditya Kumar; and Narayanan Neithalath, Arizona State University, Tempe, AZ; Missouri University of Science and Technology, Rolla, MO; Malvern PANalytical Inc., Westborough, MA

Abstract Text:

Aluminosilicates from unconventional sources offer promising potential for developing low-carbon supplementary cementitious materials (SCMs), yet their activation typically requires energy-intensive thermal processing. Kaolinite, examined in this study, is a geologically abundant and highly attractive precursor clay mineral for achieving sustainability goals in concrete production. By integrating mechano-

and thermo- chemistry in sequence in a novel hybrid mechanothermal activation (MTA) strategy for clay mineral activation, the dehydroxylation of pure kaolinite for enhanced pozzolanic reactivity is unlocked at substantially reduced temperatures below 500℃, which are typically insufficient under conventional sole thermal activation (TA). The mechanochemical (MCA) step induces significant structural defects and disorder, thereby facilitating further structural transformations that enhances reactivity of the final product. The post-milling calcination condition is guided by a robust kinetic analysis framework. Solid-state NMR reveals a progressive increase in the populations of reactive Al^{V} and Al^{IV} coordination sites, along with soluble $Q^4(mAl)$; m=0,1,..4 species, across the MCA, MTA, and TA pathways. XRD, TGA, and FTIR characterization techniques provide further insights into the extent of mineralogical evolution induced by the MTA process, which yields 25% higher reactivity relative to the precursor MCA materials under the applied post-milling thermal treatment. These findings highlight the critical influence of adopted calcination regime following MCA on the reactivity of activated kaolinite and demonstrate the potential of optimizing process parameters for energy-efficient synthesis of SCMs.

11:30am - Abstract #3857

Diapers to concrete: Upcycling absorbent waste materials as internal curing agents for more durable concrete

Halle J Block; Akul Nimish Seshadri; Kendra A. Erk; Arsen Simonyan; and Seth Lindberg, Purdue University, West Lafayette, IN; Procter & Gamble Service GmbH, and Procter and Gamble Co.

Abstract Text:

This study explores a cross-industry opportunity for valorizing absorbent material waste as internal curing agents in concrete. Superabsorbent polymer (SAP) hydrogels have been shown as promising internal curing agents for increasing the durability and therefore sustainability of concrete. Upcycled absorbent gelling materials (AGM) containing SAP from personal hygiene manufacturing processes were evaluated as internal curing admixtures for ordinary and high-performance mortars and concretes. Upcycled AGM-cured mixtures were compared alongside conventionally curing reference mixtures, as well as mixtures containing commercial polyacrylate SAP previously studied as internal curing admixtures. Autogenous shrinkage tests of high-performance mortar with 0.2% bwoc upcycled AGM displayed small but significant reduction in shrinkage strain compared to the AGM-free mortar. By increasing the dosage, and blending the AGM samples, further enhancements in autogenous shrinkage mitigation were exhibited. AGM-containing mortar and concrete displayed comparable and sometimes increased compressive strength compared to control mixtures with no internal curing. Compared to control mortar mixture designs, upcycled AGM-containing mixtures containing 0.2% dosage bwoc of absorbent material did not require additional WRA to meet flow targets, unlike the water-retentive, commercial SAP-containing mixtures which required a much larger dose to reach similar flow levels and making those mixtures more environmentally and economically more costly.

11:45am - Abstract #3905

Hydration and phase evolution in bcsa-blended PLC and LC^3 cement systems

Visa Juhani Isteri; Eric P Bescher; and Fabian Paniagua, CTS Cement Manufacturing Corporation, Garden Grove, CA; University of California Los Angeles, Los Angeles, CA

Abstract Text:

Reducing the carbon intensity of cementitious binders requires both clinker reduction and improved performance of low-clinker systems. Portland Limestone Cement (PLC) and Limestone Calcined Clay Cement (LC^3) represent two promising approaches for lowering the CO_2 footprint of conventional

Ordinary Portland Cement (OPC). However, these systems may exhibit limitations in early-age strength development and shrinkage behavior. This study investigates the incorporation of Belitic Calcium Sulfoaluminate (BCSA) cement as a functional mineral component in PLC- and LC^3-based binders to improve early performance while maintaining low-carbon benefits.

BCSA cement requires less calcium than OPC and less alumina than conventional calcium sulfoaluminate binders, and it is characterized by rapid strength development, reduced drying shrinkage, and lower global warming potential (GWP). In this work, PLC and LC^3 systems were partially replaced with BCSA to evaluate the resulting hydration behavior, phase assemblage evolution, and mechanical performance. Mechanical performance was evaluated through flexural strength, compressive strength, and drying shrinkage measurements. Hydration kinetics were characterized using isothermal calorimetry, while hydration products and microstructural development were analyzed using X-ray diffraction (XRD), thermogravimetric analysis (TGA), and electron microscopy.

The results show that incorporation of BCSA significantly accelerates early-age strength development and reduces drying shrinkage in both PLC and LC^3 systems. Hydration analysis indicates the formation of ettringite together with carboaluminate phases, reflecting interactions between the aluminate–sulfate reactions of BCSA and the carbonate-rich environment provided by limestone. In LC^3–BCSA systems, similar phase assemblages were observed, with limestone participating in carboaluminate formation and influencing sulfate–aluminate equilibria. Competition for available mixing water among hydration reactions was identified as a key factor governing hydration kinetics and phase development.

These results provide insight into the hydration mechanisms and microstructural evolution of PLC–BCSA and LC^3–BCSA binders and demonstrate the potential of BCSA as a functional component for designing high-performance, low-carbon cement systems.

F: Bio-Inspired Cementitious Materials

Thursday, June 11, 2026, 10:00am – 12:00pm

10:00am - Abstract #3877

Hydration and phase evolution in slag-clay-eggshell cement-less binders: Role of calcination temperature and composition

Bryan K. Aylas-Paredes; Duy-Hai Vo; Taihao Han; Narayanan Neithalath; and Aditya Kumar, Missouri University of Science and Technology, Rolla, MO; Arizona State University, Tempe, AZ

Abstract Text:

Cement-less binders represent a promising alternative to conventional Portland cement systems for advancing sustainable construction. This study investigates a novel binder system composed of ground granulated blast furnace slag (GGBFS) and co-calcined clay-eggshell (CCe). The CCe component was prepared at a clay-to-eggshell mass ratios of 1:1, 2:1 and 3:1 and incorporated to replace 20% of the cement-less mixture (75% GGBFS + 5% gypsum). Three calcination temperatures (650, 750, 850 °C) at 2 hours of duration were evaluated to assess their influence on hydration behavior, microstructure, and mechanical performance. Calorimetric results indicate that increasing the CCe ratios accelerates early hydration, as evidenced by amplified heat flow peaks at early reaction times. Compressive strength improved with increasing CCe ratio at lower calcination temperatures; however, the opposite trend was observed at temperatures above 750 °C. This reduction in performance is attributed to decrease in pozzolanic reactivity of the cementitious components. Despite this adverse effect at higher calcination temperatures, mixtures containing CCe ratios lower than 2:1 still achieved more than 50% at their relative strength after 91 days of hydration. Microstructural characterization revealed that calcium silicate hydrate (C-S-H), monocarboaluminate (McA), and ettringite (AFt) were the primary hydration products, with their abundances increasing with curing time. These observations were further supported by thermodynamic simulations, which predicted the evolution of hydrate phase assemblages for the investigated mixture compositions. Overall, these findings provide insights into the design and activation of binary cement-less binder systems incorporating industrial and bio-diverse waste materials.

10:15am - Abstract #3688

Calcium silicate/aluminate cements used in dentistry

Carolyn M Primus, Primus Consulting, Sarasota, FL

Abstract Text:

Calcium silicate and aluminate cements have been important for oral health since the 1990s. Remarkably, these cements are bioactive; that is, they form hydroxyapatite on their surfaces in vivo. Their lack of shrinkage, high pH, bioactivity, and biocompatibility have revolutionized endodontic treatments, enabling dentists to save more teeth from extraction. These are equally important for pediatric dentistry. The indication for use and a brief overview of their successes will be presented. An overview of the cements and additives will be presented, including some properties and standards.

10:30am - Abstract #3893

Sea sponge-inspired hard-soft cementitious composite enabled by multi-material additive manufacturing and phase field-cohesive zone model simulation

Reza Moini; Aimane Najmeddine; and Shashank Gupta, Princeton University, Princeton, NJ

Abstract Text:

Monolithic cementitious materials lack fracture resistance and are brittle. Advancements in additive manufacturing techniques and architected designs have remained limited in degrees of freedom to use a single (cement-based) constituent. This work charts a new pathway for manufacturing and designing tough, ductile, and strong architected cement-based materials by proposing a multi-material additive manufacturing (MMAM) technique, an integrated manufacturing-design-engineering approach. Cementitious mortar with elastomeric constituents (silicone and polyurethane) are exemplified, through a layered hard-soft architected design, inspired by the microstructure of a sea sponge (glass sponge Euplectella aspergillum). The MMAM technique alternates extrusion of hard-soft composites, enabling systematic control over geometry and constituents of resulting structures. The results demonstrate layered mortar-silicone composites achieved up to 3.9-and 8.8-fold enhancements in fracture toughness and up to 11.7-and 12.4-fold enhancements in ductility relative to monolithic 3D-printed (3DP) and cast mortars, respectively. A coupled large-deformation phase-field-cohesive-zone (PF-CZM) framework was used to systematically probe soft-layer thickness and bulk soft-material properties. Simulations revealed that combining higher-stiffness soft layers with reduced thickness can yield up to a 24-fold increase in work-of-fracture while recovering the load-bearing capacity of monolithic mortar. Guided by numerical predictions, experiments on thin, stiffer polyurethane interlayers validated the numerical predictions and provided additional experimental evidence that the proposed (Mortar-PU) composites achieve 82-and 187-fold higher fracture toughness, 22.6-fold more ductile, relative to 3DP and cast monolithic references, while recovering the flexural strength to levels statistically comparable to those of their counterparts. These large gains arise from three synergistic mechanisms: crack arrest/deflection, crack bridging, and discontinuous layer-wise crack re-nucleation, activated by the layered hard-soft architecture and supported by DIC/AE fracture analyses. The proposed MMAM-enabled fabrication-design-engineering approach can unleash entirely new properties, pathways, and perspectives for imagining next-generation concrete structures.

10:45am - Abstract #3914

The air-entraining effect of bio-based surfactants in alkali-activated slag pastes

Ali Ghahremaninezhad and Mohammad Sadegh Tale Masoule, University of Miami, Coral Gables, FL

Abstract Text:

The air-entraining of several bio-based surfactants with different molecular structures in alkali-activated slag pastes is examined. The influence of bio-based surfactants on air-void structure of alkali-activated slag pastes were measured. Most bio-based surfactants demonstrated moderate to high foaming stability, which is attributed to increased adsorption at bubble films. In hardened pastes, bio-based surfactants showed marked increase in air-void porosity. The correlation between foaming in solution vs air-entrained porosity was found to be week. The underlying mechanisms responsible for the air-entraining effect of bio-based surfactants in alkali-activated pastes are discussed.

11:00am - Abstract #3867

Microalgae-produced $CaCO_3$ for decarbonizing cement production

Danielle N. Beatty; Cansu Acarturk; Matthew R. Wiatrowski; Michael T. Guarnieri; and Wil V. Srubar III, University of Colorado, Boulder, Boulder, CO; Gebze Technical University, Çayırova, Turkey, National Laboratory of the Rockies, Golden, CO

Abstract Text:

In this work, we target clinker emissions reduction using photosynthetically produced $CaCO_3$ (produced by coccolithophore *Gephyrocapsa* sp.) in place of quarried limestone as 1) a nucleation seeding agent, 2) a partial cement replacement and 3) a raw material for cement clinker production. Coccoliths harvested

from *Gephyrocapsa* sp. were first characterized with respect to particle size, morphology, and mineralogy prior to incorporation into portland cement systems. Their performance as a seeding agent (0.5-5 wt%) and as a partial cement replacement (5 and 15 wt%) was evaluated using isothermal calorimetry and compressive strength testing. Their performance as a raw material for cement clinker production was characterized using bulk clinker synthesis in a laboratory box furnace, followed by phase analysis and compressive strength testing. In situ high-temperature X-ray diffraction was used to quantify phase evolution and reaction kinetics during clinkering. Results from seeding and replacement studies show that coccoliths lead to enhanced C-S-H nucleation, without accelerating hydration. Coccoliths can be used as an effective cement replacement, although enhanced water demand (due to elevated surface area of 12.2 m^2/g) likely limits their usage to < 5 wt% replacement without water reducing admixtures. Clinkering results indicate that coccoliths are an effective limestone source for cement clinker synthesis. Coccoliths enabled complete calcination at temperatures approximately 50 °C lower than cement synthesized with quarried limestone. Following calcination, coccolith clinker achieved similar phase formation to that of quarried limestone clinker. Life cycle assessment modeling suggests up to 60% emissions reduction is possible relative to conventional limestone-derived clinker. The current state of production, scalability, and economic potential/challenges of using coccoliths in cementitious materials is discussed using technoeconomic analyses. Coccoliths show significant technical and emissions reduction potential in cementitious materials but rely on successful large-scale cultivation of marine microalgae for applicability in the future.

11:15am - Abstract #3926

Cementless, recyclable biopolymer composites for construction in austere environments

Beng Wei Chong and Xijun Shi, Ingram School of Engineering, Texas State University, San Marcos, TX

Abstract Text:

Construction activities are increasingly expanding into austere environments, including polar regions, deserts, and extraterrestrial settings, where conventional cementitious materials may face significant logistical and environmental limitations. These conditions impose new requirements on construction materials, including sustainability, reduced water consumption, in-situ resource utilization, and recyclability. This study presents the development of a novel cementless biopolymer composite designed for construction in resource-limited environments. The composite formulation was optimized to achieve compressive strengths comparable to normal-strength concrete while maintaining only 50–70% of the density of conventional cementitious materials. The material also exhibited enhanced ductility and flexural strengths approximately twice those of typical cementitious composites. Unlike conventional cement hydration, the biopolymer composite gains strength primarily through desiccation, enabling recovery of more than 80% of the mixing water at maturity. In addition, a recycling approach was developed based on the reversible gelation behavior of the biopolymer matrix, allowing end-of-life composites to be recast into new composites, with an approximate 30% reduction in strength after recycling. The proposed biopolymer composite demonstrates strong potential for sustainable infrastructure development in austere and resource-limited environments.

11:30am - Abstract #3790

Evaluating internal curing efficiency of cellulose nanofibrils and impact on performance of cementitious materials

Priyan Roy Tamil Eniyan and Linfei Li, Florida International University, Miami, FL

Abstract Text:

Cement-based materials undergo volumetric shrinkage as hydration progresses and pore water is consumed to form hydration products. As hydration continues, capillary pores become partially saturated, leading to the development of pore water pressure. This internal drying process, commonly referred to as self-desiccation, results in autogenous shrinkage. When autogenous shrinkage is externally restrained and the stiffness of hydrating cement increases, tensile stresses develop and may lead to early-age cracking. These early-age cracks are a major durability concern, as they provide pathways for accelerated ingress of chlorides, sulfates, and moisture, ultimately compromising the long-term performance of concrete infrastructure. The magnitude and rate of shrinkage are governed by the evolution of pore size distribution and degree of saturation. Internal curing has been proposed as a practical approach to reduce autogenous shrinkage by supplying water from within the cementitious system. Conventional internal curing agents such as lightweight aggregates (LWAs) and superabsorbent polymers (SAPs) have been shown to reduce shrinkage and improve hydration. However, these materials present limitations related to water release rate, spatial distribution, and potential impacts on mechanical properties. Cellulose nanofibrils (CNFs) can store water within the fiber lumen and interfibrillar spaces due to their nanoscale morphology. This stored water can be released gradually as capillary suction develops during hydration, thereby maintaining a higher degree of pore saturation and reducing capillary pressure development. This study explores the feasibility of using CNFs for internal curing and evaluates the effects of internal curing water on hydration and mechanical properties of cement-based materials.

11:45am - Abstract #3938

Development and characterization of bio-permeable concrete using corn waste biochar

Nutchapon Chusai; Peerapong Jitsangiam; and Thanon Bualuang, Florida International University, Miami, FL; Chiang Mai University, Chiangmai, Thailand

Abstract Text:

Urban flooding and agricultural waste management are pressing challenges in many developing regions, where the open burning of corn residues exacerbates air pollution and greenhouse gas emissions. This study addresses both issues by utilizing corn waste-derived biochar as a sustainable fine aggregate replacement in pervious concrete.

By replacing 7.5% to 12% of natural sand by volume with pyrolyzed corn biochar, a bio-permeable concrete (BPC) was developed and optimized for light-traffic urban pavements. Comprehensive laboratory characterization and a full-scale field application demonstrated that the optimized mixture successfully met permeable pavement requirements, achieving a 28-day compressive strength of 14.7 MPa, a total porosity of 27.3%, and a permeability coefficient of 4.21 mm/s.

Microstructural analysis via scanning electron microscopy (SEM) revealed that cement hydration products, specifically C-S-H gels, effectively integrated into the biochar's tubular porous structure. This interlocking mechanism enhanced interfacial bonding and matrix densification without compromising the interconnected macro-voids necessary for stormwater drainage.

Furthermore, environmental assessments confirmed a significant carbon footprint reduction compared to conventional pervious concrete. These findings highlight the dual benefit of utilizing agricultural waste to improve infrastructure resilience against flooding while promoting sustainable, low-carbon construction practices.

G: Supplementary/Alternative Cementitious Materials (Part 1 of 2)

Thursday, June 11, 2026, 1:15pm - 3:15pm

1:15pm - Abstract #3851

Enhancing the reactivity of basalt for alkaline activation

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

Abstract Text:

This talk will highlight ongoing work investigating the effects of ball milling to enhance the viability of using lunar regolith and basalt as aluminosilicate precursors for alkali-activated materials (AAMs). Lunar Mare Simulant (LMS-1), developed to replicate the physical and chemical properties of lunar regolith, is composed primarily of terrestrial basalt and various aluminosilicate and silicate minerals. These mineral phases are highly crystalline and comparatively inert, limiting their reactivity under alkaline activation and CO_2 curing conditions. Previous experiments have demonstrated minimal dissolution of LMS component minerals, constraining aluminosilicate gel formation. Current work investigates mechanical activation via high-energy ball milling as a strategy to enhance precursor reactivity. Far-from-equilibrium dissolution experiments at high pH were conducted to quantify the impact of milling duration on the release of Si, Al, Ca, and Mg, providing insight on the availability of gel-forming species. Isothermal calorimetry was used to assess changes in reaction kinetics and heat evolution during alkaline activation. Preliminary results indicate that milling substantially increases material reactivity, with the most pronounced effects observed in glass-rich basalt fractions. While basalt has been used as a supplementary cementitious material (SCM), mechanical activation may enable its use as a primary precursor in AAM systems. These findings support the feasibility of producing carbonate-bearing, basalt-based alkali-activated materials through mechanical activation, with implications for in-situ resource utilization (ISRU) and carbon-sequestering construction materials.

1:30pm - Abstract #3768

Cost-competitive SCMs, produced anywhere cement is made

Daniel Kopp; Bahram Jadidian; Sean Quinn; Mario Davidson; Brian MacDowall; Xinglei Liu; Nick Boyko; and David Gersholowitz, Queens Carbon, Inc., Cedar Grove, NJ

Abstract Text:

Cement production accounts for approximately 7–8% of global CO_2 emissions, creating urgent demand for supplementary cementitious materials (SCMs) that enable deep clinker reduction without compromising performance or cost. Conventional SCMs are constrained by geography, variable quality, and declining industrial byproduct supply. Queens Carbon is producing a new class of engineered SCMs derived directly from limestone, sand, and clay-the same abundant raw materials used by the cement industry. By producing SCMs from conventional cement feedstocks, Queens Carbon removes supply limitations and enables scalable localized production wherever cement is manufactured.

This presentation outlines Queens Carbon's SCM production methodology, presents mortar and concrete performance data at meaningful clinker replacement levels, and evaluates projected production costs relative to clinker and traditional SCMs. Results demonstrate that engineered Q-SCMs achieve substantial clinker reduction while maintaining strength, durability, and constructability.

1:45pm - Abstract #3925

Cost effective organic molecular additive for hydration control and strength enhancement in cementitious materials

Aniket Patnaik; Jialai Wang; Monica Amaral; Ayan Saha; Abdulmaliq Alawode; Xi Chen; Maysam Bahmani; and Xinyu Shi, The University of Alabama, Tuscaloosa, AL

Abstract Text:

Reducing the carbon footprint of cementitious materials while maintaining or improving performance remains a major challenge in sustainable construction. CO_2 mineralization presents a promising pathway for sequestering the carbon dioxide in the concrete. This study investigates the influence of a low-cost sugar-derived organic additive on the hydration behavior and microstructural evolution of ordinary Portland cement with the inclusion of carbonation technology. Microstructural analysis of cement pastes at 3, 7, and 28 days reveal significant modifications in hydration product development. The particle size is seen to be more evenly distributed, increasing the packing density and improved workability. In addition, carbonation treatment of the modified system results in a substantial improvement in mechanical performance, with compressive strength of mortar samples increasing by approximately 64% and 47% by the end of 7 days and 28 days respectively. These findings suggest that regulating the CO_2 mineralization process with a small-dose admixture is a promising strategy for boosting binder efficiency and reducing clinker demand in sustainable concrete production.

2:00pm - Abstract #3988

Testing the wrong thing? Why OPC-based standards misread alternative binders

Eric P. Bescher and **Fabian Paniagua,** University of California Los Angeles, Los Angeles, CA; CTS Cement Manufacturing Corporation, Garden Grove, CA

Abstract Text:

This presentation will discuss where conventional testing frameworks can misrepresent performance in non-OPC binders. Topics will include: the mismatch between standard shrinkage test start times and real structural service onset,, especially the strength-to-drying shrinkage ratio, the relevance of early-age dimensional stability in rapid-setting systems, and limitations of surface resistivity as a durability indicator in ettringite-rich microstructures. The influence of internal self-desiccation and pore evolution on transport properties, and the broader need to align performance testing with actual chemistry and intended service conditions. Using BCSA as a case study, this talk will argue for a more chemistry-aware, performance-based approach to test method development for the next generation of low-carbon cementitious materials.

2:15pm - Abstract #3987

Center of excellence for the advancement and acceleration of cement and concrete engineering technologies (ACCENT)

Denise A Silva, Oak Ridge National Laboratory, Oak Ridge, TN

Abstract Text:

Concrete underpins modern society, and a consistent, reliable supply is essential to meeting U.S. energy and infrastructure demands. Yet, the industry remains heavily reliant on imports, even as projected growth - driven by housing shortages, replacement of aging infrastructure, new power generation, critical mineral processing, and data centers - places increasing strain on an already vulnerable supply chain. While sufficient domestic feedstocks exist to develop new cementitious materials, the lack of an intentional and coordinated development and scale-up process has slowed innovation, qualification, and adoption. ACCENT's mission is to accelerate the development and deployment of domestic materials, enabling industry to meet demand reliably and efficiently. ACCENT is an Oak Ridge National Laboratory (ORNL)–led Center of Excellence designed to help the United States cement and concrete industry to accelerate the development, validation, and deployment of next generation cement and concrete technologies, hence addressing materials supply gap, strengthening U.S. competitiveness and supporting core infrastructure needs. ACCENT will act as a trusted, third-party national hub to help the industry prove performance, qualify materials, and scale manufacturing faster, from lab results to field use. It provides coordinated access to unique pilot scale facilities, advanced characterization tools, modeling and data platforms, field validation sites, and workforce training that do not exist in one place anywhere else in the country. ACCENT is located primarily at ORNL and the National Laboratory of the Rockies (NLR). It is fully focused on the Concrete and Cement Industrial base providing the best technical expertise through its national joint faculty members and providing access to the DOE complex wide national laboratory scientific resources. Strategic and scientific guidance is provided by the Industry Advisory Board and the Science Advisory Board, respectively. The intention of this abstract is to present ACCENT to the cement/concrete academic community attending the ACerS Cements 2026 meeting.

2:30pm - Abstract #3868

Lessons from roman lime processing for modern carbon-neutral cements

Ida Marie Nervik and Admir Masic, Massachusetts Institute of Technology, Cambridge, MA

Abstract Text:

The production of modern Ordinary Portland Cement (OPC) remains a significant contributor to global CO_2 emissions, motivating a return to lime-based binders as a sustainable alternative. Recent field breakthroughs, including electrochemical production of cementitious materials, require a state-of-the-art understanding of lime as a primary binder and its pairing with pozzolans. Historically, Roman lime-based mortars have demonstrated remarkable durability by surviving millennia and exhibiting self-healing properties. This research investigates the lime cycle (calcination, slaking and carbonation) through the lens of ancient processing sequences to inspire sustainable modern binder solutions.

The methodology takes on a dual approach. First, the ancient lime processing sequence was reconstructed at a newly excavated active construction site in Pompeii. This site revealed evidence of onsite recycling, where calcite-based architectural elements were calcined and either ground into fine quicklime or slaked in large chunks for non-structural applications. Second, lime was characterized at different stages of the cycle using various spectroscopic tools to identify microstructural transformations, including vibrational spectroscopy, XRD and TEM. This treated limestone was used in a cement paste mix to investigate the effects on structural performance.

Results indicate that the progression through the lime cycle alters the crystal structure of the original limestone at the nanoscale. The resulting nanocrystals with smaller particle size and larger surface area enhance pozzolanic behavior and thus the production of CSH gels. Investigating the evidence provided in Pompeii is essential for developing long-lasting modern cement. Other applications include improving Limestone Calcined Clay Cement (LC3) systems, with potential to increase OPC substitution content.

Future work will focus on using spectroscopic tools to further map the microstructural evolution through the lime cycle and testing cement paste mixes integrated with treated lime. By learning from ancient materials with incomparable longevity, this study provides a feasible pathway to reduce OPC reliance through enhanced mineral-binder interactions.

2:45pm - Abstract #3909

Na_2CO_3 as an activator of early reactivity in limestone calcined clay cement

Lenka Scheinherrova; Hyunuk Kang; and Franco Zunino, CTU in Prague, Prague, Czech Republic; University of California, Berkeley, Berkeley, CA

Abstract Text:

Limestone calcined clay cement (LC^3) is considered a promising low-carbon binder due to its reduced clinker content and favorable synergy between calcined clay and limestone. However, the early-age performance of LC^3 systems is limited by the generally slow reactivity of the aluminosilicate component and by the kinetics of hydrate formation. This study investigates the effect of sodium carbonate (Na_2CO_3) addition on the early hydration and compressive strength development of an LC^3 binder.

The investigated LC^3 system consisted of 55 wt.% ordinary Portland cement (OPC), 30 wt.% calcined clay (Dynapozz), and 15 wt.% limestone. Four paste or mortar mixtures were prepared with Na_2CO_3 dosages of 0, 0.025, 0.075, and 0.125 wt.% of binder, while maintaining a constant water-to-binder ratio of 0.50. The main objective was to evaluate whether a small Na_2CO_3 addition can promote early pozzolanic or hydration-related reactions in the LC^3 system and improve its mechanical performance at early ages.

The experimental program includes isothermal calorimetry, X-ray diffraction (XRD), and compressive strength testing after 3 and 7 days of curing. Isothermal calorimetry is used to assess the influence of Na_2CO_3 on the early hydration kinetics of the LC^3 system, while XRD is applied to monitor phase assemblage changes associated with hydration and possible carbonate-activated reactions. Compressive strength testing is performed to evaluate the macroscopic response of the modified binder. Particular attention is given to the relationship between Na_2CO_3 dosage, hydration kinetics, phase development, and early strength evolution.

The study aims to provide an initial assessment of Na_2CO_3 as a simple chemical activator for LC^3-type binders. The results are expected to contribute to a better understanding of early-age reaction control in blended low-clinker systems and to clarify whether sodium carbonate can be used to enhance the short-term performance of LC^3 without altering its principal compositional concept.

3:00pm - Abstract #3944

Pore structure in low-carbon cement systems: Effects of cement composition and mineral additions

Aiqing Xu; Dayou Luo; Randa Zeidan; Thien Tran; Sristi Das Gupta; Paola Huynh; Maria Juenger; Kyle Austin Riding; Kejin Wang; and Kimberly E. Kurtis, Georgia Institute of Technology, Atlanta, GA; Iowa State University, Ames, IA; University of Florida, Gainesville, FL; The University of Texas at Austin, Austin, TX

Abstract Text:

Understanding how clinker replacement and constituent modification affect pore structure across multiple length scales is essential for the development of low-carbon cement systems. This study investigates the pore structure characteristics of cement systems relevant to Calcined Clay-Type IL Cement (CC·I·L) and limestone calcined clay cement (LC^3) binders, including Type IL cement from Missouri (IL-MO) and Nebraska (IL-NE), Type IP cement from Utah (IP-UT), and corresponding blends modified with calcined clay and/or limestone. Cement composition and phase assemblage were characterized by X-ray fluorescence (XRF), X-ray diffraction (XRD)/Rietveld refinement, and thermogravimetric analysis (TGA). Nitrogen adsorption and mercury intrusion porosimetry (MIP) were used to quantify specific surface area

(SSA), pore size distribution, and pore volume. The results show that pore structure is governed not only by clinker replacement, but also by source-dependent cement composition and phase constitution. IL-MO exhibited the highest SSA and adsorption-derived pore volume, whereas IP-UT showed the lowest values. In the IL-NE series, calcined clay reduced adsorption-derived SSA and pore volume and was accompanied by marked refinement of the MIP-resolved capillary pore structure. In contrast, limestone addition in the IP-UT series increased adsorption-derived SSA and pore volume, while MIP indicated a modest increase in characteristic mercury-accessible pore entry size, suggesting pore structure reconfiguration rather than simple densification. The IL-MO-based blends showed a distinct response, further highlighting strong source dependence. The results provide insight into composition-pore structure relationships in low-carbon cement systems.

H: Rheology and Additive Manufacturing

Thursday, June 11, 2026, 1:15pm - 3:15pm

1:15pm - Abstract #3850

Mechanical characterization and desiccation-driven interfacial shear degradation in extrusion-based 3D-printed cementitious mortar

Pedram Ghassemi; Lisa E Burris; Anthony Luscher; and Jeremy Seidt, The Ohio State University, Columbus, OH

Abstract Text:

The layer-by-layer deposition process in extrusion-based 3D concrete printing (3DCP) introduces interfaces that govern structural reliability. The printing time interval (PTI) controls the substrate surface desiccation state at the moment of bonding and thereby determines interface quality; yet the mechanistic link between chemical hydration evolution and interfacial shear response remains poorly established. A Portland limestone cement (PLC, Type IL) mortar was developed for 3DCP through a parametric study of ten mixes evaluated by flow table and vane shear tests. The baseline mix, bentonite-modified with silica fume and a polycarboxylate-based high-range water reducer, achieved a flow of 109% and a vane shear strength gain from 6.22 to 11.92 kPa over 60 minutes, confirming pumpability, extrudability, and buildability in printing trials. TGA conducted on substrate specimens at seven PTIs (0–960 min) revealed progressive free water depletion from 9.97% to 0.78% by PTI = 480 min, with the sharpest decline occurring between PTI = 240 and 480 min, consistent with the Vicat initial (205 min) and final (330 min) setting times of the mortar. Interfacial torsional shear tests, synchronized with 3D digital image correlation (DIC), were developed and performed across the same PTI range under four applied normal stress levels (0–1.5 MPa). Interface shear strength at zero confinement declined by 81% from PTI = 0 to PTI = 240 min (6.56 to 1.25 MPa), with the degradation concentrated over precisely the PTI range in which TGA confirmed progressive desiccation. Applied normal stress substantially preserved capacity even at fully desiccated states: at PTI = 960 min, strength increased from 2.19 MPa (zero confinement) to 5.10 MPa (1.5 MPa confinement). These results establish a direct TGA-to-mechanics linkage that quantifies open-time-dependent bond degradation and underpins interface design criteria for 3DCP elements.

1:30pm - Abstract #3934

Rheological behavior and printability of cement-blended modified high-plasticity clay mixtures for extrusion-based 3D printing

Maryam Masoomi and Pavan Akula, Oregon State University, Corvallis, OR

Abstract Text:

Three-dimensional (3D) printing with earth-based construction materials has gained increasing attention due to its availability and low environmental impact compared to conventional cement-based materials. Most existing studies on earth-based 3D-printing have focused on low-plasticity soils; however, such soils are not available in all regions, which highlights the importance of evaluating the performance and adaptability of high-plasticity soils for application in 3d printing. Moreover, the effects of the addition of cement to soil on the fresh properties of the soil-based mixtures for 3D printing have not been comprehensively studied. High-plasticity clays, especially smectites, swell and shrink due to their 2:1 layered structure and negatively charged sheets, which attract hydrated interlayer cations and increase water absorption, causing their expansion. Soil modification with lime and sand is a widely adopted method in civil engineering to reduce the plasticity of soil to make it more stable. In this study, a high-plasticity soil with a plasticity index (PI) of 56 was modified through the addition of lime and sand. Three modified mixtures were evaluated and compared with soil to determine their suitability for 3D printing applications based on their fresh properties and swelling behavior. The soil with better performance was selected to study the impact of the addition of cement on the fresh properties of the treated soil mixture. Three additional mixtures were prepared by adding cement at 10%, 20%, and 30% by dry weight of soil to the modified soil. The fresh properties of the mixtures were assessed, including rheological properties, flow table spread, extrudability, and buildability.

1:45pm - Abstract #3798

Precision of rheological parameters derived from measurements

Roman Rezaev; **Dimitri Feys;** Shravan Muthukrishnan; and Viktor Mechtcherine, Technische Universität Dresden, Dresden, Germany; Missouri University of Science and Technology, Rolla, MO

Abstract Text:

When performing rheological measurements on cement-based materials, homogeneity is assumed. In order words, the presence of particles, and their individual contributions, are typically neglected in the data analysis. However, particle contacts, grain inertia, lubrication forces and friction are local effects which naturally vary with space and time inside the material. These local affects can manifest through fluctuations in the measurements.

A typical data treatment during rheological analysis will average out these fluctuations. Sometimes, excessive fluctuations are deleted from the calculations. However, these fluctuations induce a probability range of torque values at each velocity. This probability was considered in the analysis of rheological experiments on concrete, conducted in the framework of an interlaboratory study on concrete rheometry within the DFG Priority Programme SPP 2005 'Opus Fluidum Futurum — Rheology of Reactive, Multiscale, Multiphase Construction Materials. Based on the variability of torque at each rotational velocity step, a Monte Carlo simulation was carried out to determine the variability of the calculated yield stress and plastic viscosity values. Assuming normal distributions are justified, coefficients of variation on yield stress reached up to 5%, and for plastic viscosity could reach 5-10%, depending on the rheometer and concrete properties. As a result, it is recommended to report plastic viscosity of concrete to the nearest 1 Pa s, and the yield stress to the nearest 1 Pa or 10 Pa, depending on its magnitude.

2:00pm - Abstract #3866

Printability and mechanical anisotropy of nanomodified ultra-high-performance concrete for 3D concrete printing

Shady Gomaa, The University of Alabama, Tuscaloosa, AL

Abstract Text:

Additive manufacturing of cementitious materials is an emerging technology in the construction industry that provides faster construction processes and enhanced design flexibility compared with conventional building methods. Ultra-high-performance concrete (UHPC), in particular, allows the use of thinner structural sections due to its superior mechanical performance. Consequently, integrating additive manufacturing with UHPC can produce a synergistic effect by combining structural efficiency with design freedom. However, it has been observed that concrete elements produced through 3D printing may exhibit anisotropic mechanical behavior, a characteristic that is generally absent in conventionally cast concrete. This raises the question of whether anisotropy is present in all printable UHPC mixtures. In this study, nanomodification techniques were applied to three UHPC mixtures while maintaining their printability. All essential printability requirements—including pumpability, extrudability, buildability, and shape stability—were successfully achieved. Three-layer printed specimens were then fabricated for each mixture, from which samples were extracted for mechanical testing, including uniaxial compression and splitting tensile strength tests. The results indicate that the degree of anisotropy in the mixtures is

influenced by their open time. An anisotropy factor was calculated for each mixture, and a relationship between anisotropy and rheological properties was identified.

2:15pm - Abstract #3989

Rheological modeling of cement slurries enhanced by physics-informed neural network

Chengcheng Tao; Huaisiao Yan; and Jiannan Ding, Purdue University, West Lafayette, IN

Abstract Text:

Understanding the rheological behavior of fresh cement slurries is essential for ensuring pumpability, placement quality, and long-term performance in applications such as oilwell cementing and additive manufacturing of cementitious materials. However, conventional numerical approaches for non-Newtonian flow modeling typically rely on mesh-based methods and high computational cost, limiting their applicability in complex and data-scarce engineering scenarios. In this study, a physics-informed neural network (PINN) framework is developed to model steady laminar flow of cement slurry in an inclined channel. The slurry is treated as a non-Newtonian suspension with viscosity dependent on both shear rate and particle volume fraction. By embedding governing physical laws into the neural network loss function, including momentum conservation and particle transport mechanisms, the proposed approach enables a mesh-free and data-efficient solution for coupled velocity and particle concentration fields. Parametric analyses are conducted to investigate the effects of key material and operational factors, including particle packing characteristics, inclination angle, and rheological properties. The results demonstrate that the PINN framework accurately captures the evolution of velocity profiles and particle distribution trends, with strong agreement compared to conventional numerical solutions. The approach provides a flexible and computationally efficient tool for modeling cement slurry rheology and offers new opportunities for integrating AI-driven modeling into cement-based materials design and processing. It highlights the potential of physics-informed learning to support advanced cementing operations and emerging digital construction technologies.

2:30pm - Abstract #3990

Chemical and rheological evolution governing the early-age behavior of alkali-activated low-grade calcined clay pastes

Sriramya D Nair and **Neel Bhuskute**, Cornell University, Ithaca, NY

Abstract Text:

Low-grade calcined clays (LCCs) represent a low-cost precursor alternative to commercial high purity metakaolin (MK) for alkali activation. Their fresh-state properties and early-age kinetics, however, remain relatively underexplored because of variations in mineralogical compositions. This study examines the fresh-state behavior and early performance of alkali activated pastes prepared from three LCC precursors and one MK precursor through an integrated evaluation of rheology, reaction kinetics, and mechanical performance. Despite slower reaction kinetics, LCC systems followed similar reaction pathways and developed comparable polymeric networks, with performance governed more strongly by reaction yield and network refinement than by reaction rate. LCC pastes exhibited improved workability at lower water contents ($w/b \approx 0.6$) relative to MK systems, which required higher water contents ($w/b \approx 0.9$) to achieve workable consistency. Small-amplitude oscillatory shear (SAOS) testing resolved four distinct rheological stages, with the end of Stage III correlating closely with measured set times across all systems. Elevated curing temperatures accelerated reaction kinetics but did not consistently translate to proportional strength gains. Activator chemistry, particularly Na/Al ratio and silica modulus, together with curing temperature, emerged as dominant tunable parameters governing early-age behavior in LCC-based alkali-activated systems.

2:45pm - Abstract #3954

Toward multifunctional concrete: Rheology control and architected supercapacitors in electron-conducting carbon-cement (ec^3) composites

Santiago El Awad; Damian Stefaniuk; Abdelmounaim Mechaala; Admir Masic; and Franz Josef Ulm, Massachusetts Institute of Technology, Cambridge, MA

Abstract Text:

Concrete's low cost and exceptional load-bearing capacity have made it the world's most widely used construction material. Recent advances have introduced multifunctionality by incorporating nano-carbon black (nCB) into cement matrices, forming a percolated electron-conductive network — yielding electron-conducting carbon-cement (ec^3) composites. This added conductivity unlocks transformative structural applications, including self-heating pavements and cement-based energy storage, positioning everyday infrastructure as an active participant in the renewable energy transition.

However, nCB's high specific surface area and hydrophobic character significantly stiffen ec^3 pastes, raising water demand and compromising workability. This work investigates two complementary strategies to improve fresh-state rheology: surface chemistry modification through chemical functionalization, and optimization of particle morphology — most importantly the oil absorption number (OAN), a measure of the structured void volume within nCB aggregates. Both approaches independently yield substantial reductions in water-to-cement (w/c) ratio, demonstrating that rheological control in ec^3 systems is achievable through targeted nCB design.

Building on improved constructability, we further advance the architected cement-based supercapacitor by developing a fully monolithic structural design. Rather than relying on conventional noncohesive separators and current collectors — which require prestressing to maintain electrochemical and structural compatibility — we introduce cohesive cement-based separators and current collectors, eliminating the incompatibility between electrochemical components and the cementitious matrix. Together, these innovations chart a path toward ec^3 systems that are both buildable and functional, bringing cement-based energy storage closer to real-world structural deployment.

3:00pm - Abstract #3910

Toward one-part alkali-activated metakaolin via inter-grinding: Assessing rheology and reaction mechanism

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

Abstract Text:

The development of alkali-activated materials (AAMs) is one of the pathways for cement decarbonization, the production of which currently contributes 5-8% of global anthropogenic carbon emissions. However, extensive deployment of AAMs in industry has yet to be realized, partially due to the reluctance to work with “two-part” activation that requires handling large amounts of concentrated caustic solutions. Here, we have investigated a “one-part” AAM, where the dry mixture of precursor and solid activator (dry mix) is combined with only water, resembling the hydration of OPC. The dry mix was prepared through inter-grinding (simultaneous grinding of the dry constituents) using a planetary ball mill. Calcined kaolinitic clay (metakaolin) was chosen as the aluminosilicate precursor due to the global abundance of kaolin clay compared to resource limited fly ash and blast furnace slag. While studies on conventional two-part AAM rheology have typically focused on assessing the effect of activator properties, this work provides a new perspective in the context of one-part AAM systems by altering the properties of the dry powder through grinding. Grinding is found to broaden the particle size distribution of the dry powder and alters the surface chemistry of the metakaolin. This in turn affects the yield stress and viscoelasticity of the resulting

fresh paste, leading to improved workability. The impact of grinding on the reaction kinetics has also been investigated using isothermal conduction calorimetry, where reaction behavior (via heat flow) has been compared with evolution of the rheological properties.

I: Supplementary/Alternative Cementitious Materials (Part 2 of 2)

Friday, June 12, 2026, 10:00am – 12:00pm

10:00am - Abstract #3952

Structure - reactivity relationships in thermally activated coal slurry for low-carbon cement

Abdulmaliq Alawode; Maysam Bahmani; Aniket Patnaik; Xi Chen; Monica Amaral; Ayan Saha; Xinyu Shi; and Jialai Wang, The University of Alabama, Tuscaloosa, AL

Abstract Text:

Coal slurry generated during coal preparation is a significant industrial byproduct whose disposal creates considerable environmental and storage concerns. This study investigates its valorization as a supplementary cementitious material through thermal activation. X-ray diffraction (XRD) revealed quartz, illite, and kaolinite as the dominant phases in the slurry, accompanied by residual carbon. Thermogravimetric analysis (TGA) guided calcination at 650 ℃ and 800 ℃ to remove carbon and activate aluminosilicate phases without recrystallization. The calcined materials were incorporated as partial cement replacements at 5 and 15 wt.% and evaluated for workability and compressive strength up to 28 days. Fourier transform infrared spectroscopy (FTIR) spectral deconvolution indicated a shift toward higher proportions of Q^1+Q^2 silicate species leading to increased relative bridging oxygen (RBO) after calcination, suggesting enhanced depolymerization and reactivity. Mortars containing 5 wt.% of the 800 °C calcined slurry exhibited strength comparable to the control at 28 days, while the 15 wt.% replacement showed reduced early-age strength but approached control performance with curing. The results highlight a clear structure–reactivity–performance relationship, demonstrating that calcinated coal slurry can serve as a promising low-carbon supplementary cementitious material while enabling sustainable valorization of coal processing waste.

10:15am - Abstract #3746

Carbon plasma process for low carbon clay activation

Kyle Wong; Joycelyn Liang; and Franco Zunino, University of California, Berkeley, Berkeley, CA

Abstract Text:

Calcined clay is a crucial ingredient in blended cements for reduced concrete carbon emissions and enhanced concrete durability, but still has a carbon footprint due to fossil fuel-powered calcination. With the push for blended cements like Portland Limestone Cement (PLC) and Limestone Calcined Clay Cements (LC3), the need for continuous, efficient, and sustainable calcined clay production is key to the construction materials industry. This study proposes a new electricity-based calcination process involving a carbon-based plasma arc torch to provide the required heat for phase transformation of common clays (kaolinite, illite, etc.) into usable supplementary cementitious materials (SCMs). X-ray diffraction and scanning electron microscopy are used to determine the crystallographic and morphological differences between calcined clay from the new calcination process and industry-convention calcined clay, while chemical reactivity (R3) and mechanical testing is used to compare the reactivity and performance of the clays as an SCM. It is anticipated that the plasma calcination process will yield calcined clays of similar if not better performance than conventional calcined clays due to higher peak temperatures and reduced residence times producing greater amorphous contents and potentially highly-reactive metastable polymorphs, all while having overall reduced carbon emissions compared to the conventional calcination processes.

10:30am - Abstract #3858

Mechanical performance and conductive behavior of nano-reinforced magnesium phosphate mortars

Myrsini Maglogianni, Wayne State University, Detroit, MI

Abstract Text:

Alternative cement chemistries are increasingly being explored to diversify cementitious materials and enable new functionalities beyond structural performance. Magnesium phosphate cement (MPC) has attracted attention due to its rapid reaction kinetics, high early strength, and chemically distinct binder system. In this work, carbon nanotubes (CNTs) were introduced into MPC mortars at low dosages ranging from 0.02 to 0.10 wt% of binder to evaluate their influence on mechanical performance and conductivity.The CNT-modified mortars showed consistently higher strength of about 15–30% compare to plain MPC. Electrical resistivity measurements indicated substantial changes in transport behavior, with reductions approaching 1–2 orders of magnitude depending on CNT content and dispersion. These results suggest that CNTs facilitate the development of conductive networks within the heterogeneous MPC microstructure. The nanotubes act as nanoscale bridges connecting hydration products and reducing electron transport resistance through the cement matrix. The combination of enhanced mechanical performance and reduced electrical resistivity highlights the potential of nano-reinforcement strategies for tailoring the functional properties of alternative cement systems. Understanding the interactions between CNT networks and MPC reaction products provides insight into the broader design of multifunctional cementitious materials within emerging alternative binder technologies.

10:45am - Abstract #3960

Carbonate-mediated activation of ultra-high-volume slag blended cement system using sodium carbonate

Samira Hossain; Zhanzhao Li; and Kai Gong, Rice University, Houston, TX

Abstract Text:

Ultra-high-volume slag blended cement (UHVS-BC) and sodium carbonate-activated slag systems both offer substantial potential for reducing clinker consumption and associated CO_2 emissions, yet they suffer from slow hydration kinetics and delayed strength development. This study investigates the activation of a UHVS-BC binder containing 90 wt.% ground granulated blast furnace slag and 10 wt.% Portland cement (PC) using sodium carbonate (Na_2CO_3). Results show that increasing Na_2CO_3 dosage can significantly enhance UHVS-BC reactivity and produce compressive strength comparable to that of a 100% Portland cement reference.

To elucidate the underlying mechanisms, isothermal calorimetry, in situ and ex situ quantitative X-ray diffraction, Fourier-transform infrared spectroscopy, and thermodynamic modeling were performed to track hydration kinetics, phase evolution, and pore-solution chemistry as a function of time. The results show that Na_2CO_3 dosage governs the balance between early carbonate precipitation and the development of sustained alkalinity. Increasing dosage shifts the reaction pathway from limited activation to a staged process in which transient carbonate precipitation moderates early reactions while enabling prolonged slag dissolution at later ages. In the highest-dosage system (20 wt.% Na_2CO_3), slag dissolution proceeds concurrently with carbonate formation, producing sustained hydroxide-dominated pore-solution chemistry and continuous gel formation. The slag reaction degree reaches ~60% at 180 days, leading to the highest gel fraction, lowest predicted capillary porosity, and compressive strength approaching that of the OPC reference. Cradle-to-gate life-cycle assessment indicates a 55–70% reduction in global warming potential relative to OPC, depending on the alkali production pathway and electricity mix. These results identify carbonate- and PC-mediated control of pore-solution alkalinity as the key mechanism governing sustained slag reaction in UHVS-BC and Na2CO3 activated slag systems.

11:00am - Abstract #3935

Design and multi-response optimization of ternary metakaolin–pumice–limestone powder geopolymer system

Taofiq O Mohammed and Ebenezer O Fanijo, Georgia Institute of Technology, Atlanta, GA

Abstract Text:

Geopolymers synthesized through the alkali activation of aluminosilicate precursors such as fly ash (FA), metakaolin (MK), and slag have emerged as promising alternatives to ordinary Portland cement due to their ability to form durable aluminosilicate gel networks. However, broader implementation remains constrained by uncertainties in precursor dissolution kinetics, variability in aluminosilicate reactivity, and limited control over reaction product formation that governs binder performance. For instance, FA-based systems predominantly form N-A-S-H gels with relatively slow reaction kinetics, whereas slag-based systems generate C-A-S-H gels associated with rapid strength gain but increased shrinkage. MK-based systems also primarily form N-A-S-H gels but often exhibit higher shrinkage. Consequently, blended precursor systems have been proposed to promote hybrid gel formation and balanced engineering performance. Recently, pumice and limestone powder (LP) have attracted attention as alternative precursors due to their abundant availability and favorable silica–alumina–calcium chemistry. Pumice provides reactive silica and alumina suitable for alkali activation, while LP modify reaction pathways and microstructure through filler and Ca-driven effects that promote hybrid C-(N)-A-S-H gel formation. However, the *compositional balance required* to control dissolution kinetics, C-(N)-A-S-H gel system, and engineering performance in ternary MK–pumice–LP geopolymer systems remains largely unexplored.

This study investigates, for the first time, the design and multi-response optimization of ternary MK–pumice–LP geopolymer mortars. An augmented simplex lattice mixture design is employed to systematically explore the ternary compositional space and quantify the influence of precursor proportions on flowability, compressive strength development, sorptivity, and drying shrinkage. Multi-response optimization is then used to identify mixture compositions that achieve balanced engineering performance. The findings provide insights into precursor synergy and binder composition optimization for geopolymer systems utilizing widely available natural resources, supporting the development of sustainable cementitious materials for low-carbon construction.

11:15am - Abstract #3904

Influence of limestone content in cement on the hydration kinetics of cement pastes with nontraditional and natural pozzolans

Anelya Zhussupekova; Alberto J Castillo; Raikhan Tokpatayeva; and Jan Olek, Purdue University, West Lafayette, IN

Abstract Text:

The growing adoption of Type IL cement in concrete has led to significant research on its influence on performance and durability of concrete. At the same time, nontraditional and natural pozzolans (NNPs) are emerging as an alternative to traditional supplementary cementitious materials (SCMs) as they become scarcer. Previous studies have shown that the incorporation of NNPs can improve durability of concrete by refining its microstructure. Although some studies have examined the synergistic effects of limestone and NNPs in concrete, they primarily focused on the external addition of limestone as a partial substitution for Ordinary Portland cement (OPC). Therefore, this research investigates the influence of varying limestone contents, from 8% to 12%, in Type IL cements on hydration kinetics of cementitious composites containing NNPs. To evaluate these effects, a total of twelve combinations of pastes were prepared using three commercially available Type IL cements and three NNPs, namely volcanic ash, calcined clay and ground bottom ash. Reference mixtures were made with inert filler at the same

replacement level (25%) as those with NNPs. Isothermal calorimetry was used to characterize hydration kinetics, while thermogravimetric analysis was performed to quantify portlandite (CH) consumption at different ages. Results indicate that performance of mixtures with NNPs is dependent on limestone content, with certain combinations showing more favorable behavior. Generally, addition of NNPs in combination with higher percentage of limestone reduced CH content due to their pozzolanic activity and decreased the total heat release. Incorporation of NNPs also influenced hydration kinetics, in some cases modifying the timing of peaks and affecting setting behavior. Most favorable behavior was observed in the combination of calcined clay and 11% limestone, while ground bottom ash showed to be the least effective material.

11:30am - Abstract #3948

Validation of 5-min UR^2 test on a dataset of 140+ calcined clays

M. Farjad Iqbal; Yujia Min; Bayezid Baten; Syed Rafiuzzaman; and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL

Abstract Text:

Calcined clays are emerging SCMs that can meet the growing demand for alternative binders. However, one of the challenges in large-scale production is the lack of a rapid, QC/QA test method. In 2025, we introduced a novel Ultra-Rapid Reactivity (UR^2) test that predicted the reactivity of 47 calcined clays within 5-minutes via low-cost colorimetry. Here, we extend and validate UR^2 using an additional 94 commercial clay samples, increasing the total dataset size to 141. Across this extended dataset, our 5-min UR^2 continues to reliably predicts 7-day R^3 heat ($R^2 = 0.9$, RMSE = 78 J/g). In addition, for a subset of diverse samples, the 5-min UR^2 shows a strong correlation with the 28-day SAI ($R^2 = 0.8$, RMSE ~11%) and 7-day bound water ($R^2 = 0.9$, RMSE = 0.96 g/100g) – a reactivity parameter recently included in ASTM C1912 performance-based specification of SCMs. Finally, to assess its robustness, we evaluated within-lab multi-operator effect and report a coefficient of variation of 3.9%. Overall, UR^2 enables ultra-rapid screening of potential, new clay sources as well as real-time production-line QC, allowing production of a consistent material at scale.

11:45am - Abstract #3936

Alkali-modified clinoptilolite zeolite as a reactive supplementary cementitious material from early-age performance to later-age durability

M. Shariful Islam and Joseph J. Biernacki, South Carolina State University, Orangeburg, SC; Tennessee Technological University, Cookeville, TN

Abstract Text:

Clinoptilolite–Ca zeolite exhibits limited pozzolanic activity at early ages in Portland cement systems, resulting in slower hydration and reduced early-age strength development. Previous studies addressed this limitation by converting Ca-zeolite into Na- or K-forms through cation exchange, which maintained a highly alkaline pore solution and enhanced hydration reactivity. Building on this concept, the present study investigates the performance of partially alkali-modified clinoptilolite zeolite treated with $Ca(OH)_2$ as a reactive supplementary cementitious material, evaluating its influence from early-age performance to later-age durability at cement replacement levels up to 20%. To achieve this modification, 100 g of Ca-zeolite powder was chemically treated using 1000 mL of 1 M $Ca(OH)_2$ solution in a sealed stainless-steel container, supplying additional calcium while maintaining a relatively high-pH pore solution (~12.5). Material characterization using X-ray diffraction (XRD) and scanning electron microscopy with energy-dispersive spectroscopy (SEM–EDS) confirmed the effectiveness of the chemical treatment and compositional changes in the zeolite. Early-age hydration kinetics up to three days were evaluated using

isothermal calorimetry, setting time measurements, and thermogravimetric analysis, while later-age performance was assessed through compressive strength, chemical shrinkage, drying shrinkage, and alkali–silica reaction (ASR) testing. The results showed that $Ca(OH)_2$-treated zeolite enhanced silicate and aluminate reactions in the cement system, as indicated by increased C_3S and C_3A peak heat release rates. Acceleration of the aluminate reaction shortened the dormant period, shifting the C_3A peak to earlier times and reducing setting times. While 5–20% replacement with untreated zeolite reduced compressive strength by up to 30%, mixtures containing 5–10% $Ca(OH)_2$-treated zeolite exhibited comparable or slightly higher (~5%) strength relative to the control. Additionally, $Ca(OH)_2$-treated zeolite mixtures showed reduced drying shrinkage at 90 days and significantly lower ASR expansion (60–90%). Overall, $Ca(OH)_2$-treated zeolite improved hydration reactivity and durability performance of blended cementitious materials.

J: Material Characterization Techniques

Friday, June 12, 2026, 10:00am - 12:00pm

10:00am - Abstract #3826

Quantifying iron sulfide superstructures in concrete aggregates in the recovered solids after density-based separation

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

Abstract Text:

The oxidation of iron sulfides, especially pyrrhotite and framboidal pyrite, is a relatively recent degradation mechanism encountered in northeastern USA, resulting in millions of dollars of litigation. These minerals undergo oxidation and damage concrete due to volumetric expansion and secondary sulfate attack, even if present in very low concentrations (*i.e.,* <0.5% by weight). Because of very low concentration, it is very difficult to quantify the concentrations of iron sulfides present in the samples. X-ray diffraction (XRD) is the only rapidly available bulk material analysis technique that can detect and quantify minerals. However, XRD units are limited by low detection capacity (2-5%) to provide comprehensive trace mineral quantification. Because of the lack of means to directly quantify the iron sulfides, indirect qualitative or semi-quantitative assessments, *e.g.*, thermomagnetic responses, selective leaching, oxygen consumption, accelerated mortar bar test, staining test, total sulfur content, *etc.*, are employed. However, to employ these indirect methods, several key assumptions are made, e.g., pyrrhotite being the only sulfide in sample, oxygen consumption is only due to pyrrhotite, *etc*. This study involves direct quantification of the iron sulfides present in samples and the actual polytypes utilizing the higher densities of iron sulfides (density > 3.5 gm/cc). As the majority of the gangue minerals present in the concrete aggregates have density less than 2.8 gm/cc, suspending aggregate particles in a heavy liquid, lithium metatungstate (LMT) (density ≈ 2.95 gm/cc), can settle the heavier minerals. These settled particles are concentrated with iron sulfides to such an extent that routine XRD measurements can quantify the iron sulfides with significant accuracy. Moreover, due to pyrrhotites being highly concentrated in the settled samples, XRD can differentiate between different polytypes. This method quantifies the presence of pyrrhotite, pyrites and other potential iron sulfides not only readily but also with high reliability.

10:15am - Abstract #3995

Optimizing supplementary cementitious material blends for concrete enhancement

Amir Hajibabaee, Ozinga Bros, Chicago, IL

Abstract Text:

Calcined clays are increasingly used as supplementary cementitious materials (SCMs), yet predicting their reactivity remains challenging because performance depends on both feed mineralogy and calcination conditions, and laboratory datasets are typically small and source specific. In this work, Self-Validating Ensemble Models (SVEM) were implemented via the SVEMnet R package to model a comprehensive laboratory dataset comprising five kaolinitic clay sources and 64 measurements spanning calcination temperatures of 600 to 800 °C and residence times of 30 to 90 min. Measured responses include R3 reactivity (isothermal calorimetry heat release) at 1 to 3 days, amorphous content, degree of dehydroxylation, and bound water. Two complementary targets were evaluated: (i) absolute properties across sources and (ii) within-source delta responses relative to a low-severity baseline to reduce cross-source shift. Using grouped-cell cross-validation (source by temperature by time), parsimonious absolute models using only calcination temperature, calcination time, and raw kaolinite content achieved R^2 = 0.907 to 0.913 for R3 reactivity (RMSE 38.07 to 44.76 J/g), R^2 = 0.947 for amorphous content (RMSE 3.81 wt%), and R^2 = 0.870 for mean bound water (RMSE 0.97 wt%). Delta models using calcination temperature and time, raw kaolinite, and baseline and delta dehydroxylation achieved R^2 = 0.737 to 0.786

for ΔR3 reactivity (RMSE 27.44 to 35.76 J/g) and $R^2 = 0.990$ for Δamorphous content (RMSE 1.14 wt%), while Δmean bound water remained less predictable ($R^2 = 0.600$). Beyond prediction, we introduce source-specific reactivity window and quality offset analyses that provide mechanistic interpretation by identifying diminishing-returns plateaus in activation state space and quantifying systematic source effects consistent with differences in amorphous quality. Overall, the results demonstrate that SVEM offers a transparent, small-data-appropriate framework for predicting and interpreting calcined clay activation while supporting anonymized workflows.

10:30am - Abstract #3892

Improving concrete performance for transportation infrastructure

Jill Rotherham; Clare Fischer; and **Christopher Shearer**, South Dakota School of Mines and Technology, Rapid City, SD

Abstract Text:

Low strength concrete failing to meet standards set by the South Dakota Department of Transportation (SDDOT) were investigated through a literature review, a statistical analysis, a review of historical test data, interviews with concrete technicians, and a survey to concrete suppliers and other state DOTs. The effects of changing water content, air content, materials, curing conditions, and processing variables were assessed on concrete by measuring fresh properties, compressive strength, and bulk resistivity. Furthermore, a forensics and petrographic assessment was performed on cored samples for low strength concrete in the field. Correlations were found between increased air contents and higher ambient temperatures and increased strength failures when analyzing historical data. Field testing revealed higher curing temperatures than allowed by specification. A nationwide DOT survey concluded that while there is not a single perceived reason for their low strength issues, specimen handling and extreme temperatures appear to be significant contributors. Experimental results showed that significantly lower compressive strengths were correlated with higher air content, higher curing temperatures, retempering at high temperatures, higher w/cm, and the use of a different coal ash. Changing these variables, especially in combination, resulted in 28-day compressive strengths lower than 4500psi indicating that the structural concrete specification can result in strength failures. Bulk resistivity of the concrete was less affected by these changing variables. The specifications should be updated to address issues including re-qualifying mix design strengths for higher air contents and incentivizing lower air contents on hot days, better quality control for batch plant and in-field concrete adjustments and fresh concrete curing procedures, changing the acceptance procedure for 28-day strength to require three cylinders, and more strictly enforcing and changing the mix design qualification procedures.

10:45am - Abstract #3922

Elemental analysis of concrete pore solutions in emerging binder systems using x-ray fluorescence (XRF)

Mohammad Houshmand; Kenneth A. Snyder; Irem Efe; and Scott Jones, National Institute of Standards and Technology (NIST), Gaithersburg, MD

Abstract Text:

The pore solution of cementitious materials plays a central role in hydration, phase stability, and degradation processes in concrete. As a result, its composition provides critical information for durability assessment and service-life prediction. This study had two objectives: first, to develop Wavelength-Dispersive X-ray fluorescence (WD-XRF) methodology for quantifying elemental concentrations in concrete pore solutions; second, to apply that methodology to pore solutions extracted from emerging cement systems, including Portland limestone cement (PLC), calcium aluminate cement (CAC), and calcium sulfoaluminate cement (CSA), with OPC replacement levels ranging from 10% to 100%. For XRF analysis, a systematic framework was established that included controlled sample preparation, calibration

model development, spectral post-processing, model verification, and quantitative uncertainty assessment. The workflow targeted sodium (Na), potassium (K), calcium (Ca), sulfur (S), aluminum (Al), and chloride (Cl) as key dissolved constituents of cementitious pore solutions. Element-specific XRF measurement uncertainty was quantified, yielding propagated uncertainties of 39%, 16%, 15%, 13%, 23%, and 16% for Na, K, S, Al, Ca, and Cl, respectively, over the investigated concentration ranges. Validation using synthesized pore solution samples independent of the calibration dataset showed that predicted concentrations for K, S, Al, Ca, and Cl remained within propagated uncertainty bounds. Although Na exhibited higher relative uncertainty in some cases, thermodynamic-based pH-constrained equilibrium modeling indicated that this variability produced only limited deviations in calculated hydroxide concentration and pH within the investigated domain. The methodology was then applied to emerging binder systems using five replicates per mixture at a water-to-binder ratio of 0.5. Samples were sealed-cured at 23 ± 0.1 °C and evaluated at different ages and OPC replacement levels. The results showed that pore solution chemistry varies significantly with binder composition and age, influencing key solution characteristics relevant to durability, including corrosion mechanisms, passivation behavior, and critical chloride conditions associated with reinforcing steel corrosion.

11:00am - Abstract #3991

Decoupling the dehydroxylation and amorphization of kaolinite upon thermal and mechanochemical activation for use in low-carbon cements

Hao Chen and Franco Zunino, University of California Berkeley, Berkeley, CA

Abstract Text:

Concrete is the second most consumed material on Earth after water. Portland cement, as the principal ingredient of concrete, has a carbon-intensive production process, accounting for 6–8% of global anthropogenic CO_2 emissions. Among various cement decarbonization strategies, clinker substitution plays a crucial role, potentially contributing to 2.85 Gt of cumulative carbon reduction by 2050 under the 2°C scenario. However, the global supply of fly ash and slag - currently the most widely used supplementary cementitious materials (SCMs) – is projected to decrease in the coming decades due to the decarbonization of power plants and steel production facilities. To sustain the momentum of clinker substitution, the industry must pivot to alternative SCM sources. In this respect, calcined clays have emerged as a scalable alternative due to their widespread global abundance and their potential to produce low-carbon concrete with uncompromised performance, such as Limestone Calcined Clay Cement (LC^3). The calcined clay typically used for SCM applications is metakaolin, derived from the activation of kaolinite. In its raw form, kaolinite is a stable, inert 1:1 phyllosilicate exhibiting negligible pozzolanic activity under normal hydration conditions. To become reactive, kaolinite must undergo activation. The traditional approach of activating kaolinite is through calcination where the kaolinite heated in a high temperature furance (typically 600–800 °C), utilizing thermal energy to induce dehydroxylation. It is a general consensus that dehydroxylation leads to amorphization, which in turn results in higher metakaolin reactivity. However, a recent study on the calcination of kaolinite between 650–1050 °C reveals that this relationship is in question. It was shown that while full dehydroxylation is completed by 650 °C according to TGA results, XRD patterns indicate that the characteristic basal kaolinite reflections only fully disappear between 700–750 °C. Furthermore, kaolinite calcined at 800 °C shows the maximum total heat evolution, indicating peak reactivity. This twofold temperature mismatch reveals a gap between the dehydroxylation process, the degree of amorphization, and the resulting pozzolanic reactivity. A more recent approach to activating kaolinite is through mechanochemical activation, which involves grinding the mineral in a high-energy mill (typically a planetary or ball mill) to utilize mechanical energy to induce amorphization. However, the underlying mechanisms of mechanochemical activation remain a subject of debate. Some studies suggest that activated kaolinite particles develop an amorphous shell while

retaining a crystalline core, whereas others report that this amorphous shell is in fact partially dehydroxylated. This raises the question of the extent to which dehydroxylation is responsible for amophization and reactivity: is mechanical activation causing pure physical amorphization, or is it also triggering a certain extent of dehydroxylation? Traditional techniques such as SEM, XRD, and TGA cannot address these fundamental questions regarding thermal and mechanical activation due to resolution constraints. This project aims to utilize a nanometer-spatial resolution technique, specifically TEM nano-diffraction (4D-STEM), to approach these issues with the goals of: 1) determining the mechanisms between 600–800 °C that are responsible for further amorphization and reactivity improvement during thermal activation; and 2) determining if the kaolinite amorphization originates from pure fracture or a combination of fracture and dehydroxylation during mechanochemical activation. The hypotheses are that: 1) the extra thermal energy during thermal activation allows further delamination and structural reorganization responsible for further amorphization and reactivity improvement; and 2) the amorphization during mechanochemical activation originates from the combination of fracture and dehydroxylation, and the extent of dehydroxylation depends on mechanical grinding parameters. The novelty of this project is twofold. From a decarbonization standpoint, this study provides insights into a fundamental understanding of dehydroxylation, amorphization, and reactivity through both thermal and mechanical activation pathways. These insights will foster improved industrial practices for kaolinite activation and optimize the reactivity of metakaolin. Consequently, this work supports the use of calcined clay as a scalable solution to the projected shortage of traditional SCMs, enabling the large-scale adoption of low-carbon cements (e.g., Type IT) both globally and nationally. From a methodological standpoint, this study pioneers the use of advanced TEM nano-diffraction (4D-STEM) to characterize activated clays for cement applications. This work will establish systematic testing protocols, including specialized sample preparation for 4D-STEM, providing a unique benchmark for future studies related to clay minerals. Furthermore, the application of this technology offers a powerful tool for investigating the fundamental chemistry of other natural pozzolans, ultimately maximizing their reactivity for sustainable construction. More specifically, the project uses 4D-STEM to characterize and compare the near-surface crystallinity of five key samples: high-purity kaolinite synthesized through the hydrothermal method, metakaolinite calcined at 600 °C (full dehydroxylation), 700 °C (full amorphization), and 800 °C (maximized reactivity), along with mechanically activated metakaolinite. Preliminary 4D-STEM data collected from high-purity kaolinite and metakaolin calcined at 600 °C and 800 °C have enabled the derivation of Automated Crystal Orientation Mapping (ACOM). These initial results reveal a distinct loss of long-range order as calcination temperatures increase, alongside the observation of a visible amorphization front. These findings validate the feasibility of 4D-STEM for characterizing the structural evolution of activated clays. Future work will expand 4D-STEM data collection across the full suite of thermally and mechanochemically activated samples, with results cross-validated against traditional TGA, XRD, and R3 reactivity tests to establish a comprehensive multi-scale understanding of clay activation.

11:15am - Abstract #3805

Identifying premature deterioration in cementitious materials using volatilomics

Oluwaseun Ayooluwa Jegede; Jenna Diefenderfer; Trenton Davis; Heather D Bean; and Jason H Ideker, Oregon State University, Corvallis, OR; Arizona State University, Tempe, AZ

Abstract Text:

Alkali-silica reaction (ASR) is a complex concrete deterioration mechanism that remains difficult to recognize and track, especially in its early stages. Since its first detection in the 1940s, various forensic techniques have been used to identify ASR in concrete. This research introduces volatilomics as a potential technique to assess ASR-related deterioration. Damaged and sound concrete have different pH levels that support the existence of various microorganisms, leading to the hypothesis for this work: bacteria in different pH environments emit distinct VOC profiles indicative of damaged or sound concrete.

Concrete exposed for at least 15 years to marine and non-marine environments was analyzed using a comprehensive two-dimensional gas chromatography with time-of-flight mass spectrometry. An optimized VOC sampling methodology was developed for concrete, which contains a high adsorbed water content. Visual observations, expansion measurements, and SEM/EDX were used to confirm the mechanisms of deterioration. ASR-related cracking and reaction products increased with depth but decreased with the inclusion of preventive measures. Also, non-marine-exposed concrete exhibited more indicators of concrete damage than marine-exposed concrete. Furthermore, distinct bacterial VOC profiles were identified, demonstrating that volatilomics may distinguish between sound and damaged concrete. In the future, this may provide a non-destructive and/or minimally invasive technique to provide early detection of concrete deterioration.

11:30am - Abstract #3885

Probing the very early-stage hydration of cements, and cement phases, using in-situ x-ray diffraction

Tu-Nam Nguyen; Enzo Amah; Lily Allen; Kimberly E. Kurtis; Thomas C. Fitzgibbons; and Angus P. Wilkinson, Georgia Institute of Technology, Atlanta, GA; Dow, Inc., Lake Jackson, TX

Abstract Text:

In-situ X-ray diffraction has been widely used to investigate hydration in cementitious systems. However, most studies begin measurements several minutes after the start of hydration as sample preparation and instrument setup take time. As a result, the earliest stages of hydration, where rapid dissolution and precipitation reactions occur, are often not observed. An experimental apparatus was developed that uses electronically controlled valves to introduce the mix water to the sample capillary, allowing for simultaneous data collection. The apparatus was used at the Advanced Photon Source beamline 11-ID-B at Argonne National Laboratory to investigate the first 30 minutes of hydration of several cementitious systems (at a time resolution of 10 seconds), including portland cement and three calcium sulfoaluminate cements. Individual cement phases – C_3S, C_3A with and without gypsum, C_4AF with and without gypsum, and ye’elimite with and without gypsum and anhydrite – were also examined. In selected experiments, 0.02% alkanolamine (triisopropanolamine, triethanolamine, and diisopropanolamine) admixtures were added to the mix water to evaluate their influence on early dissolution and precipitation reactions. These measurements provide new insights into early cement hydration pathways.

11:45am - Abstract #3903

Evolving cement microstructure via nanosilica additions using nuclear magnetic resonance spectroscopy

Alexis Scida; Keith Fritzsching; Nelson Bell; Melissa Mills; and Jessica M Rimsza, Sandia National Laboratories, Albuquerque, NM

Abstract Text:

Nanosilica additions to portland cement pastes are known to increase strength and improve durability due to formation of a denser and more cohesive microstructure driven by increased pozzolanic reactions that refine the pore structure. Reactivity of the nanosilica particles is dependent upon the surrounding minerology, including portlandite content, and the microstructure and pore solution compositions vary during hydration. Given the complexity of the hydration process highly sensitive advanced characterization techniques, including nuclear magnetic resonance (NMR), analysis can provide fundamental insight into evolution of cement pastes with and without nanosilica. Here, cement pastes with nanosilcia additions up to 5 wt% were synthesized. Time-dependent x-ray diffraction data and ^{43}Ca, ^{29}Si, and ^{27}Al NMR spectra using the windowed-CPMG detection scheme for efficient data collection were used to evaluate the role of nanosilica in evolution of mineral phases during hydration. The results focus

not just on evolution of the silica species during formation of C-S-H but extend to evolution of the calcium and aluminum species in C3A and C4AF phases with relevance for indexing spectra in additional cement compositions, such as calcium aluminate cements. The results identify how evolution of volumetrically minor phases are altered by increased silica dosages for understanding of sensitivity of the cement paste microstructure to nanosilica additions. *SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525*

Poster Session

Wednesday, June 10, 2026, 4:45pm – 7:00pm

Abstract #3699

High-SCM 3D-printed mortars for marine conditions

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

Abstract Text:

This study investigates the printability and mechanical and durability-related performance of 3D-printable Portland limestone cement (PLC) mortars incorporating high amount of supplementary cementitious materials (SCMs) for marine applications. Mortars containing 40–60% fly ash or calcined clay were evaluated using an extrusion-based 3D-printing system. Printability was assessed through flowability, extrudability, open time, and buildability, with image-based methods used to quantify extrudability and layer deformation. Compressive strength and bulk electrical resistivity of cut one-inch cubes were measured at 91 days. Printed specimens are currently being stored in seawater for long-term mechanical and durability evaluation. Results indicate that high-SCM mortars exhibit acceptable printability and extended open time, with most mixtures achieving structural-grade strength. Increased electrical resistivity with SCM incorporation suggests improved resistance to ionic transport, supporting the feasibility of high-SCM 3D-printed mortars for marine infrastructure.

Abstract #3724

Influence of supplementary cementitious materials on the potential corrosion of steel reinforcement in low-carbon concrete

Paola Huynh and Maria Juenger, University of Texas at Austin, Austin, TX

Abstract Text:

The performance of low-carbon concrete is heavily contingent upon the integration of supplementary cementitious materials (SCMs). The interaction between SCMs and the cementitious matrix fundamentally alters the alkalinity and chemical composition of the pore solution, which may affect the corrosion risk of embedded reinforcement steel. It is essential to comprehend the extent of these effects to determine how it will impact long-term durability of low carbon concrete.

This study will examine how steel reinforcement potentially corrodes in low-carbon concrete and the process of designing corrosion-resistant low-carbon concrete structures using low-carbon materials. Selected materials will be characterized using isothermal calorimetry, quantitative x-ray diffraction, thermogravimetry analysis, and rapid, reliable, and relevant testing to aid in predicting their pore solution reactivity. Paste will be tested to determine fresh state properties by using mini-slump and isothermal calorimetry. As testing progresses further testing will be conducted on mortar samples to evaluate the potential effect of low-carbon materials on reinforcement.

Abstract #3761

Atomistic insights into radiation effects on borosilicate glasses using molecular dynamics

Chaima el Malki, USMS, Beni Mellal, Morocco

Abstract Text:

Borosilicate glasses, used for the immobilization of high-level nuclear waste, are subjected to intense energetic radiation during their storage in deep geological repositories. However, the effects of such irradiation on their atomic structure remain poorly understood. In this context, the present study relies on molecular dynamics simulations to investigate the structural alterations induced by irradiation in a series of sodium- and calcium-containing borosilicate glasses, with Si/B molar ratios ranging from pure silicate to pure borate compositions.

Abstract #3773

Mild activation of slag-metakaolin alkali-activated concrete using potassium carbonate

Sujan Phuyal and Linfei Li, Florida International University, Miami, FL

Abstract Text:

Potassium carbonate (K_2CO_3) offers low-causticity, lower-carbon alternative to conventional hydroxide- and silicate-based activators. However, its activation and durability performance remains poorly understood, particularly in blended aluminosilicate systems. This study comprehensively investigates the potential of using potassium carbonate as a sustainable activator for ground granulated blast-furnace slag (GGBFS)-metakaolin (MK) blended concrete. Potassium carbonate-activated concrete with 0 - 25% MK replacement by wt. was produced at constant binder content, water-to-binder ratio, and activator concentration. Mechanical performance, durability to aggressive chemical attack (sulfate and chloride resistance), and water uptake via capillary pores were measured, along with reaction kinetics and phase evolution, with MK replacements. Reaction kinetics and hydrated-phase evolution were characterised using isothermal calorimetry, X-ray diffraction, Scanning Electron Microscopy coupled with Energy-Dispersive X-ray Spectroscopy, and thermodynamic equilibrium modelling with GEMS. Results identify a narrow optimal MK range (10-15%) that maximises reactivity and microstructural refinement, increasing 28-day compressive strength from around 33 MPa to 36 MPa and doubling bulk resistivity by 28 days despite a mildly alkaline activation environment; however, water absorption didn't follow the same trend. All mixtures exhibited low sulfate-induced expansion (≤0.049% at 28 weeks), with MK improving microstructure and reducing sulfate-induced expansion. Microstructural analyses reveal dominant K-A-S-H and C-(A)-S-H gels with calcite- and hydrotalcite-like phases; an isothermal calorimeter indicates a very short induction period, with the peak acceleration period reached within four hours of mixing, signifying a reaction pathway distinct from that of sodium-carbonate-based systems.

Abstract #3775

Plasma electrification of kaolinitic clay calcination for cementitious binders

Ellie A. Vaserman and Claire E. White, Princeton University, Princeton, NJ

Abstract Text:

Calcined clays are of great interest for reducing the energy and raw material intensity of cement through their use in alternative binders and as supplementary cementitious materials (SCMs). Among these, metakaolin (MK), the thermally activated form of kaolinitic clay (Al2Si2O5(OH)4), is abundant and well-studied, as forms durable C-A-S-H phases during partial clinker replacement, improving the strength, durability, and resistance to chemical attacks in cementitious systems. In parallel, MK serves as a

precursor for alkali-activated materials (AAMs), which are Si- and Al- rich binders that form geopolymeric networks without limestone calcination. However, the production of MK is energy intensive, with conventional kilns requiring sustained temperatures of 700–1100 °C achieved through fossil fuel combustion. Plasma offers a promising sustainable pathway for the complete electrification of calcination by providing rapid and controllable heating. Plasma systems also introduce unique reactive environments that can accelerate kaolin amorphization, potentially enhancing MK reactivity. In this work, the effects of a low-temperature, non-equilibrium plasma jet on kaolinitic clays was analyzed using in situ diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS) paired with complementary material characterization through thermogravimetric analyses and X-ray diffraction. This research aims to advance fundamental understandings of how plasma heating affects kaolinite dehydroxylation and amorphous phase development, defining the fundamental processing windows and conditions for producing high-reactivity MK.

Abstract #3816

Thermal activation of recycled cement to produce novel supplementary cementitious materials

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

Abstract Text:

The concrete industry is a significant contributor to global CO_2 emissions, primarily due to the calcination of limestone in clinker production. Recycled cement/concrete products offer a scalable pathway to mitigate the CO_2 emissions of the concrete industry. We investigate here the upcycling of recycled cement paste (RCP) as a supplementary cementitious material (SCM) through controlled thermal activation and air quenching. Several RCP materials with varied composition were thermally activated at 400 °C, 600 °C, and 800 °C with a residence time of 2 hours. Thermal treatment of hydrated cement paste induces the progressive dehydration of C–S–H along with other hydrates, ultimately leading to the formation of high-temperature crystalline phases such as β-C_2S, along with the generation of free lime in certain systems. In contrast, SCM-blended systems exhibit distinct phase evolution pathways due to their higher silica and alumina contents, which influence decalcification reactions and solid-state transformations at elevated temperatures. This study systematically investigates the high-temperature phase assemblages formed in these systems. The reactivity of the thermally activated recycled cement pastes (RCPs) is also subsequently evaluated. Thermal activation enabled the synthesis of supplementary cementitious materials exhibiting heat release values exceeding 150 J/g SCM, comparable to those of Class F fly ash.

Abstract #3830

CO_2 uptake in fillers and supplementary cementitious materials

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

Abstract Text:

Carbonating fillers and supplementary cementitious materials (SCMs) prior to their incorporation into cementitious mixtures offers a promising strategy for CO_2 sequestration while maintaining the performance of SCM-blended systems. This study investigated the carbonation behavior of fillers (raw, mechanochemically activated, and thermally activated) and SCMs with CaO + MgO contents ranging from 6–50%. CO_2 uptake and phase changes were evaluated using thermogravimetric analysis (TGA), Fourier transform infrared spectroscopy (FTIR), and X-ray diffraction (XRD). The effect of carbonation on material reactivity was assessed using a modified R^3 test. Recycled cement materials and steel slags exhibited substantial CO_2 uptake, whereas other materials showed generally low carbonation potential. Mechanochemical activation induced physical and chemical changes that slightly enhanced carbonation. Overall, CO_2 uptake in the powders had minimal impact on the reactivity of the fillers and SCMs.

Abstract #3839

Engineering sustainable concrete for improved coral settlement on artificial reefs

Kylee Rux and Prannoy Suraneni, University of Miami, Coral Gables, FL

Abstract Text:

In the wake of intensifying climate change combined with ever-increasing populations in coastal regions, there is a critical urgency in protecting our coastlines and ecosystems. Submerged offshore structures, known as artificial reefs, have emerged as a solution for ecological improvement, habitat preservation, and coastal defense. However, the use of traditional concrete in artificial reef construction raises concerns related to its carbon footprint, poor ecological performance, and susceptibility to erosion. This study investigated the use of modified cementitious materials to enhance natural coral larvae settlement on artificial reefs, leading to increases in biodiversity and coastal protection. The role of chemical cues in larval settlement was explored, motivated by previous evidence that coral larvae exhibit attraction to calcium carbonate-rich substrates in natural reef systems. Experimental cement paste tiles (3 x 3 cm) were developed with various chemical modifications alongside sustainable cement industry practices, including the use of supplementary cementitious waste products and carbonation curing to mitigate carbon emissions. Two approaches were evaluated: (1) uncarbonated tiles incorporating direct mineral additives (limestone, olivine, sodium carbonate), and (2) carbonated tiles combining supplementary cementitious waste products (fly ash, slag) and carbonation curing to precipitate calcium carbonate phases. Tiles were conditioned in seawater and exposed to coral larvae of *Colpophyllia natans* over a 20-day settlement period in a temperature-controlled chamber. Tiles of each modification were tested in individual glass jars (n = 8) with 50 larvae per jar. Particle tracking methods were also used to quantify larval swimming behavior during the settlement period. Results demonstrated higher settlement on uncarbonated tiles relative to the carbonated tiles. Sodium carbonate-containing tiles exhibited significantly higher settlement than all other tiles. By incorporating minerals that serve as chemical cues in conventional concrete mixes, artificial reefs can be engineered to promote biological recruitment, contributing to reef restoration efforts and coastal resilience.

Abstract #3848

Data-driven strength prediction and design space exploration of concrete containing waste brick powder

Jiabao Zhai, Rice University, Houston, TX

Abstract Text:

Global construction and demolition activities generate large quantities of waste clay brick, most of which is landfilled. Waste brick powder (BP), produced from demolished clay brick debris, has attracted increasing interest as a supplementary cementitious material. However, its effective utilization in blended cement systems remains challenging due to the large variability in composition, mineralogy, and reactivity of waste BP. In this study, we develop a chemistry-informed, data-driven framework for performance prediction and design space exploration of blended cement concrete containing BP. A comprehensive database comprising more than 2,000 data points was curated from the literature, spanning mixture proportions, chemical and physical attributes, and curing conditions. A Reactive Alumino-Silicate Content (RASC) index was introduced as a chemistry-informed material descriptor to approximate the intrinsic reactivity of brick powder. Multiple machine learning models were trained to capture nonlinear relationships governing strength development with high predictive accuracy. Model explainability techniques were applied to quantify the influence of mixture parameters and raw material characteristics. The trained surrogate models were further integrated with cradle-to-gate CO2 emissions and material cost assessments to explore the feasible design space of BP-containing concrete mixtures. The results demonstrate the capability of the proposed framework to identify mix designs that balance mechanical

performance, cost, and environmental impact, providing a systematic pathway for the circular utilization of brick waste in sustainable concrete production.

Abstract #3860

Structural performance of 3D-printed SEAHIVE® units for coastal protection

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

Abstract Text:

Coastal communities face increasing risks from sea-level rise, storm intensity, and shoreline erosion, highlighting the need for resilient coastal protection systems. SEAHIVE®, a modular coastal protection system developed at the University of Miami, consists of perforated hexagonal units designed to dissipate wave energy while promoting marine habitat. This study evaluates the structural performance of full-scale SEAHIVE units fabricated using extrusion-based 3D printing of cementitious mortar. Units were produced with three internal geometries (hexagonal, dodecagonal, and circular) and three reinforcement configurations: unreinforced, GFRP reinforcement grouted immediately after printing, and GFRP reinforcement grouted after a 72-hour delay. Structural behavior was assessed through four-point bending tests on full units and compressive tests on cut sections, with deformation and cracking monitored using Digital Image Correlation. Reinforcement significantly increased flexural and compressive capacity compared with unreinforced units. However, considerable variability among specimens was observed, highlighting the need for improved quality control and reinforcement integration in 3D-printed coastal infrastructure.

Abstract #3879

Physical and mechanical properties of two-part alkali-activated pastes utilizing calcined low-grade kaolin clay

Sarah Paschke and Claire E. White, Princeton University, Princeton, NJ

Abstract Text:

With the growing interest in developing solutions to combat greenhouse gas emissions associated with the production of ordinary Portland cement (OPC), calcined kaolin clays have emerged as sustainable supplementary cementitious materials (SCMs) for use via partial replacement of OPC or an aluminosilicate precursor for alkali-activated materials (AAMs). To date, the use of calcined high-grade kaolin clay (i.e., metakaolin) in OPC and AAMs has been well-documented, providing important insight on the process by which metakaolin reacts in these systems. However, availability of metakaolin on a global scale is limited, and the high-cost associated with its high-purity level further detracts from its use in the construction industry. Recent developments show the viability of calcined low- and medium-grade kaolin clays in OPC and AAM systems, however, the performance of resulting AAM concrete remains largely unknown. In this work, the physical and mechanical properties of two-part AAM pastes synthesized using metakaolin and calcined low-grade kaolin clay have been determined and benchmarked against Portland limestone cement (PLC) counterparts. Compressive strength has been evaluated together with dynamic modulus measurements. Moreover, the extent of efflorescence has been investigated to assess the mobility of the alkali ions. This study helps to better understand the potential of calcined low- and medium-grade kaolin clay for use as AAM precursors where the resulting binder can serve as a viable industrial solution.

Abstract #3886

Integrated thermal and mechanochemical processing of calcined clays for low-carbon cementitious systems

Maysam Bahmani; Jialai Wang; Xinyu Shi; Xi Chen; Abdulmaliq Alawode; Aniket Patnaik; and Ayan Saha, The University of Alabama, Tuscaloosa, AL

Abstract Text:

Reducing clinker consumption is essential for lowering the carbon footprint of cement, motivating the development of alternative supplementary cementitious materials (SCMs). Calcined clays are promising candidates due to their global availability and relatively low activation temperature; however, current research focuses primarily on thermal activation while the role of post-calcination processing remains poorly understood.

This study investigates an integrated thermal–mechanochemical processing strategy to enhance the performance of calcined clays in cementitious systems. Two clay sources, Lake Nicol (LN) clay and Seattle kaolin (SK), were calcined between 750 and 900 °C and evaluated using R^3 calorimetry, thermogravimetric analysis (TGA), X-ray diffraction (XRD), and isothermal calorimetry of cement pastes containing 15% calcined clay replacement. To address agglomeration during grinding, xylitol-assisted mechanochemical co-grinding was implemented and compared with conventional milling.

Results show that calcination at 850 °C yields maximum intrinsic pozzolanic reactivity for both clays. Xylitol-assisted co-grinding produces finer and narrower particle size distributions while improving particle dispersion. Consequently, cement pastes containing co-ground calcined clays exhibit enhanced flowability and increased compressive strength relative to conventionally processed systems. The findings demonstrate that calcined clay performance is governed by the combined effects of thermal activation and mechanochemical processing, providing a pathway for improving the efficiency of locally sourced clays in low-carbon cementitious materials.

Abstract #3888

LC^3 pastes produced with non-kaolinitic clays from phosphorus mining: Strength development and microstructural characteristics

Duy-Hai Vo; Bryan K. Aylas-Paredes; Taihao Han; Narayanan Neithalath; and Aditya Kumar, Missouri University of Science and Technology, Rolla, MO; Arizona State University, Tempe, AZ

Abstract Text:

Phosphate clays—byproducts generated during the phosphorus mining—are rich in SiO_2, Al_2O_3, and CaO, providing chemistries that may be suitable for use as SCMs following thermal activation. In this study, five clays collected from different locations in Florida, USA, were evaluated to assess their pozzolanic reactivity and suitability for limestone calcined clay cement (LC^3) applications. Pozzolanic reactivity was quantified using a modified R^3 test, while LC^3-50 binders were prepared by replacing 50% of Portland cement. Calcined clay-to-limestone mass ratios of 1:1, 2:1, 3:1, and 4:1 were investigated to identify optimal mixture proportions. The results demonstrated a strong correlation between the quantified reactivity and compressive strength of LC^3 systems. The primary hydration products identified include C-(A)-S-H, ettringite, monocarboaluminate (McA), and hydrotalcite (Ht), with their abundances increasing as both calcined clay reactivity and the calcined clay-to-limestone ratio increased. Elevated P_2O_5 contents significantly delayed hydration and reduced pozzolanic reactivity, whereas higher MgO contents accelerated hydration and promoted Ht formation, which in turn suppressed McA formation. All LC^3 pastes achieved compressive strengths exceeding the strength activity index threshold of 0.75 at 28 days, confirming the technical feasibility of incorporating phosphate waste clays into LC^3 binder systems.

Abstract #3897

Mechanisms governing carbonate polymorphism and core–shell formation during wet carbonation of OPC and RCF

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

Abstract Text:

The wet carbonation method has been acknowledged as a promising CO_2 sequestration method, with the potential to valorise Ca-rich waste. However, the understanding of carbonation behaviour among different waste systems remains limited. The present study systematically investigates the influence of solid waste (OPC and RCF), the liquid-to-solid ratio (L/S) and tannic acid (TA) on carbonation efficiency, morphology regulation and strength improvement. The pH, conductivity, temperature, and ion concentration of the solution were simultaneously monitored to track the evolution of the polymorph formation. The results indicate that carbonation products are predominantly particles with $CaCO_3$ shell and silica core. RCF demonstrated a substantially higher carbonation efficiency (72.6%–77.9%) than OPC (26.9%–51.3%), with the process being completed within 30 minutes. OPC exhibited a greater potential to regulate the morphology of $CaCO_3$ crystals, while the phenomenon is sensitive to a delicate balance of gas flow and ion concentration, involving L/S ratios and TA. The role of TA is multi-faceted, functioning as a calcite stabiliser, leaching agent and retarder, thereby enhancing carbonation efficiency, reducing energy consumption and improving mortar strength. The precursor reactivity and solution chemistry jointly govern carbonate polymorphism and internal phase evolution. These findings provide insights into the wet carbonation mechanism and highlight its potential for CO_2 mineralisation and functional SCMs for applications of other Ca-rich wastes, e.g. CKD, FGD gypsum, fly ash, steel slag, phosphate taillings, etc.

Abstract #3902

Self-healing performance of hydrogel-modified cementitious materials in marine environments

Farzad Rezaeicherati and Ali Ghahremaninezhad, University of Miami, Coral Gables, FL

Abstract Text:

Marine concrete structures are prone to premature deterioration because service-induced cracks allow seawater (SW) to penetrate, promoting chloride and sulfate ingress and accelerating damage. This study investigates hydrogel-enabled self-healing in cementitious materials under marine-relevant exposure, focusing on how hydrogel-driven moisture uptake and release influence the formation and chemistry of crack-filling products. Two hydrogel systems (H2 and H3) were incorporated into Ordinary Portland Cement (OPC) and Portland Limestone Cement (PLC) pastes and conditioned under cyclic W/D regimes in deionized water (DIW) and SW to emulate realistic moisture transport and ionic environments. Crack closure was quantified using digital microscopy. The evolution of healing products and crack-interface features was examined using TGA, FTIR, and SEM/EDS. By integrating visual crack-closure tracking with phase and microstructural characterization, this study aims to provide a mechanistic framework for understanding hydrogel-assisted autonomous crack sealing in both benign and marine conditions. The findings are expected to help guide the design of more resilient self-healing cementitious systems for coastal and offshore infrastructure.

Abstract #3907

Mechanistic insights into early-age surface resistivity of calcined clay and LC3 blended cements

Mohammad Zunaied Bin Harun and Ebenezer O Fanijo, Georgia Institute of Technology, Atlanta, GA

Abstract Text:

Calcined clay (CC)-based binders have emerged as promising low-carbon alternatives to ordinary Portland cement (OPC) due to their supply of reactive aluminosilicates that promote the formation of additional C-A-S-H phase gel and aluminate-bearing hydration products such as ettringite and AFm

phases. The development of these phases contributes to pore structure refinement while simultaneously modifying pore solution chemistry through alkali uptake and redistribution within hydration products. Because ionic transport in cementitious materials is governed by both pore connectivity and pore solution conductivity, these coupled microstructural and chemical changes can significantly influence *durability-related transport properties*. Surface resistivity (SR) is widely used as a non-destructive indicator of transport resistance; however, its interpretation in CC-based systems remains unclear, particularly at early ages when hydration reactions, phase assemblage, and pore solution chemistry evolve rapidly. This complexity may be further complicated in limestone–calcined clay cement (LC3) systems, where additional interactions among carbonate, aluminate, and silicate phases modify hydration pathways and pore solution composition. Consequently, SR responses in CC and LC3 binders may differ substantially from those observed in OPC systems. This study, therefore, develops a mechanistic framework linking the early-age evolution of SR to hydration reactions, phase assemblage, and pore solution conductivity in CC and LC3 cement systems. By integrating SR measurements with microstructural and chemical characterization, the study elucidates the roles of alkali binding and phase development in controlling ionic transport during early hydration. The results provide new insight into transport mechanisms in CC-based binders and improve the reliability of SR as a durability indicator for emerging low-carbon cementitious materials.

Abstract #3912

Functionalization and pre-carbonation of algae biochar for carbon neutral/negative cementitious composites

Jasmine Victoria Rodriguez and Ali Ghahremaninezhad, University of Miami, Coral Gables, FL

Abstract Text:

Algae blooms across Florida and the Caribbean have been disturbing ecosystems and causing logistical nightmares for coastal communities needing to remove and dispose of the organic material. This project utilizes Florida-native algae converted to biochar which is then functionalized with various chemical activation techniques to improve properties such as water absorption, porosity, adsorption of CO_2, and overall binding to the cement matrix. By functionalizing the algae biochar, our goal is to replace higher contents of cement than seen in previous studies. By functionalizing and pre-carbonating algae biochar we aim to promote $CaCO_3$ formation leading to more durable and resilient cementitious composites. Pre-carbonating biochar allows for further carbon sequestration and the potential to produce carbon negative cementitious composites. In this presentation, various characterization techniques, including Thermogravimetric analysis (TGA), Fourier transform infrared spectroscopy (FTIR), Scanning electron microscopy (SEM/EDX), Brunauer-Emmett-Teller (BET), are used to study the chemical attributes and microscopic properties of the cement-biochar composites. Mechanical properties are examined using compressive and flexural strength tests. Electrochemical impedance spectroscopy (EIS) is employed to assess the durability of the materials.

Abstract #3915

Mechanistic interpretation of biofuel-based combustion synthesis for next generation cement manufacturing

Sayee Srikarah Volaity; Shubham Agrawal; Aditya Kumar; and Narayanan Neithalath, Arizona State University, Tempe, AZ; Missouri University of Science and Technology, Rolla, MO

Abstract Text:

Biofuel-based combustion synthesis (BCS) is emerging as a low-carbon, low-energy route for the production of lime and clinker phases by harnessing heat released from biofuel combustion within reactive pellets; however, the process involves strongly coupled heat transfer, gas transport, and sequential solid-state reactions. Because experiments generally provide only surface temperature

histories and final phase assemblages, they offer limited access to the internal mechanisms controlling conversion and product formation. To address this limitation, a coupled multiphysics transport-reaction model was developed for the BCS synthesis of β-dicalcium silicate (β-C2S, belite), in which transient energy, momentum, and species conservation equations were solved together with kinetic expressions for lignin combustion, limestone calcination, and belite formation. Fuel-combustion kinetics were calibrated using dedicated experiments, and the model was validated against experimental results, enabling direct resolution of internal thermal and reaction fields that are inaccessible experimentally. Building on these simulations, a wavefront propagation analysis was performed, enabling identification and quantification of thermal, combustion, calcination, and synthesis fronts through their velocities, trajectories, and spatial coverage. This analysis revealed that belite formation is governed less by the peak temperature attained than by the pellets, with product yield correlating strongly with the extent to which the high-temperature synthesis wavefront traverses the pellet interior under competing effects of heat generation, heat loss, and reactant accessibility. Taken together, the multiphysics framework and wavefront-based interpretation provide a mechanistic basis for understanding, predicting, and optimizing BCS, thereby supporting the design of next-generation low-carbon cement manufacturing processes.

Abstract #3916

Closing the loop on cement: Flash recycling of hydrated cement paste into reactive clinker

Chanyeong Park, Civil and Environmental Engineering, Rice University, Houston, TX

Abstract Text:

Hydrated cement paste (HCP) fraction of demolished concrete is typically landfilled, locking cement manufacturing into a fundamentally linear model. Here, we introduce an electrified flash recycling process (FRP) that converts waste HCP back into reactive, OPC-like clinker within 60 s. FRP employs intense Joule heating to raise temperatures above 1600 °C within seconds, decomposing hydration products and regenerating highly reactive clinker minerals while suppressing the formation of non-reactive polymorphs. Extensive characterization, including QXRD, ICC, TGA, FTIR, Raman spectroscopy, and strength test, reveals that the resulting flash-recycled cement (FRC) exhibits mineralogy, hydration behavior and mechanical performance similar to conventional OPC. Life-cycle assessment indicates that the FRP route reduces energy demand by ~40% and CO_2 emissions by ~60% relative to conventional OPC production, with reductions exceeding 90% when powered by renewable electricity. Techno-economic analysis suggests ~35% lower production costs, with the potential for near-zero net cost when accounting for demolition waste tipping fees. By regenerating standard OPC chemistry, FRP enables immediate compatibility with existing specifications while supporting decentralized, electrified waste recycling, establishing FRP as a viable pathway for circular, low-carbon waste cement recycling.

Abstract #3917

Effect of biomass source and pyrolysis temperature on the structure and physicochemical properties of biochar

Mohammad Hosein Moghadasin and Sivakumar Ramanathan, University of Miami, Coral Gables, FL

Abstract Text:

Biochar is a heterogeneous carbonaceous material whose properties depend strongly on biomass source and pyrolysis conditions. This study compares biochars produced from hardwood, softwood, and agricultural residues under a systematic processing matrix spanning pyrolysis temperatures of 300–700 °C and two residence times – 30 and 60 minutes. The influence of biomass source and processing conditions on biochar yield, morphology, porosity, and overall physicochemical behavior are evaluated. Feedstocks are pre-conditioned standardized drying, size reduction, screening, and homogenization procedures to minimize variability unrelated to source and processing history. The resulting chars are being evaluated using complementary structural, thermal, and chemical characterization methods such as

BET, XRF, SEM, Water absorption, etc. The effect of biomass source and processing temperature on biochar structure and physicochemical properties will be presented, with an emphasis on how these variables govern the development of application-relevant features. This work provides a comparative framework for understanding source–processing-property relationships in biochar and for guiding the selection of feedstocks and pyrolysis conditions for targeted material performance.

Abstract #3920

Boxcrete: A Bayesian optimization open-source AI model for concrete strength forecasting and mix optimization.

Bayezid Baten; **Muhammad Ayyan Iqbal**; Sebastian Ament; Julius Kusuma; and Nishant Garg, University of Illinois Urbana Champaign, Urbana, IL; META, Menlo Park, CA

Abstract Text:

Modern concrete must simultaneously satisfy evolving demands for mechanical performance, workability, durability, and sustainability, making mix designs increasingly complex. Recent studies leveraging Artificial Intelligence (AI) and Machine Learning (ML) models show promise for predicting compressive strength and guiding mix optimization, but most existing efforts are based on proprietary industrial datasets and closed-source implementations. Here we introduce BOxCrete, an open-source probabilistic modeling and optimization framework trained on a new open-access dataset of over 500 strength measurements (1–15 ksi) from 123 mixtures—69 mortar and 54 concrete mixes tested at five curing ages (1, 3, 5, 14, and 28 days). BOxCrete leverages Gaussian Process (GP) regression to predict strength development, achieving average $R^2 = 0.94$ and RMSE = 0.69 ksi, quantify uncertainty, and carry out multi-objective optimization of compressive strength and embodied carbon. The dataset and model establish a reproducible open-source foundation for data-driven development of AI-based optimized mix designs.

Abstract #3927

Biomolecule-regulated carbonation of recycled concrete fines for enhanced CO_2 sequestration and reactivity

Xi Chen; Xinyu Shi; Monica Amaral; Abdulmaliq Alawode; Maysam Bahmani; Aniket Patnaik; Ayan Saha; Armando Gabriel McDonald; Jialai Wang; Augustine Sackey, The University of Alabama, Tuscaloosa, AL; University of Idaho, Moscow, ID

Abstract Text:

This study proposes a biomolecule-regulated carbonation (BioCarb) strategy to improve the carbonation efficiency and reactivity of recycled concrete fines (RCF) derived from end-of-life concrete. Three representative biomolecular regulators, a polyol, a polyphenol, and tannins extracted from Douglas Fir Bark, were introduced as small-dose additives during aqueous carbonation to regulate calcium dissolution and carbonate precipitation. Experimental results show that biomolecular regulation significantly accelerates carbonation kinetics. Within 10 min, the carbonation efficiency increased from 44.7% under conventional carbonation to 87–95% with biomolecular regulators. Notably, the tannin-based regulator demonstrated particularly strong early-stage carbonation kinetics, substantially enhancing the carbonation efficiency within the first 10 min. Near-complete carbonation was achieved within 60 min, whereas conventional carbonation reached only 88.6% under the same conditions. Biomolecule regulation also significantly modified the pore structure of carbonated RCF. The BET surface area increased from 63 m^2/g under conventional carbonation to 90 m^2/g with polyol addition, indicating a significantly more porous carbonate structure. Mortars incorporating the polyol-regulated carbonated RCF exhibited a 20% higher 28-day compressive strength compared with the control mixture. These results demonstrate that biomolecule regulation provides an effective strategy to accelerate carbonation, enhance the reactivity of carbonated RCF, and produce highly reactive carbon-negative SCMs for sustainable cement production and CO_2 sequestration.

Abstract #3929

Development of sustainable repair mortars and sewerage pipe concrete materials incorporating reclaimed asphalt pavement and recycled steel fibers

Md Nasir Uddin; Xijun Shi; and Zachary Grasley, Texas State University, San Marcos; Texas A&M University, College Station, TX

Abstract Text:

The construction sector faces increasing pressure to reduce its environmental footprint by minimizing the use of natural aggregates and conventional steel reinforcement in cement-based materials, particularly for applications such as repair materials and sewer pipes. This study investigates sustainable repair mortars and dry-cast pipe mixtures incorporating reclaimed asphalt pavement (RAP) aggregate and recycled steel fibers (RSF) to promote circular construction and divert waste from landfills. RAP gradation was determined through particle size analysis, and its density and specific gravity were measured to support mixture proportioning. For developing repair materials, RAP replaced natural sand at 20%, 40%, and 60% by volume in mortar mixtures. RSF recovered from scrap tires were incorporated at 0.5–1.25% by volume to enhance crack resistance and tensile performance. Fresh properties were evaluated using flowability and mini-slump tests, while hardened performance was assessed through compressive strength, flexural strength, indirect tensile strength, ultrasonic pulse velocity, and dynamic modulus measurements. Bond performance was further evaluated using a slant shear test. Results indicate that increasing RAP content reduces workability and compressive strength due to higher absorption and residual asphalt; however, mixtures containing 20% RAP maintained compressive strengths comparable to the control mixture. The addition of RSF significantly enhanced tensile behavior, increasing flexural strength to 10.3 MPa, approximately 30–40% higher than fiber-free mixtures. For dry-cast pipe mixtures containing 3/8 in. limestone aggregate and a water-to-cement ratio of 0.29, incorporating 0.75–1.0% RSF produced stable pipe formation, 28-day compressive strengths of 45–54 MPa, and adequate shape retention for early demolding. These results demonstrate that RAP and RSF can be effectively combined to produce durable, low-carbon materials suitable for specific applications.

Abstract #3940

Atomistic mechanisms of ion transport in CNASH nanopores

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Abstract Text:

Ionic transport in cementitious nanopores plays a critical role in long-term durability and applications such as heavy-metal immobilization. However, the molecular-scale mechanisms governing the mobility of different ions in cementitious nanopores remain poorly understood, particularly in alkali-activated materials (AAMs). Here, classical molecular dynamics simulations were used to investigate the transport of ten aqueous cation species (including Na^+, K^+, Cs^+, Ca^{2+}, Cd^{2+}, Ba^{2+}, Mg^{2+}, Pb^{2+}, Sr^{2+}, and Zn^{2+}) in a sodium-containing aluminum-substituted calcium–silicate–hydrate (C–(N)–A–S–H) nanopore, representing gel pores in high-Ca AAM systems. The results show that nano-confinement significantly reduces ion diffusivity relative to the bulk solution, largely due to strong cation adsorption at the gel surface, particularly at surface Al–OH sites. The extent of diffusion retardation and the associated diffusion energy barriers vary considerably among cations and are governed by a recently introduced total coordination-strength parameter that reflects intrinsic ionic properties such as electrostatic density and hydration structure. These findings provide new insight into the molecular factors controlling ion mobility in AAMs and highlight the importance of both surface chemistry and intrinsic ionic properties in governing transport processes relevant to concrete durability and contaminant immobilization.

Abstract #3941

Quantitative characterization of fracture surfaces and crack-space information in concretes with different water-to-binder ratios

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Abstract Text:

A three-dimensional digital characterization method was developed to quantitatively evaluate fracture surface morphology and crack-space information in concretes with different water-to-binder ratios. Cylindrical specimens (Φ50 × 100 mm) were subjected to diametral splitting tests using a modified loading configuration with a polished steel wire to achieve near-line loading and promote stable crack propagation along the specimen diameter. After splitting, the two fracture surfaces were digitized using a high-resolution 3D laser scanner with a spatial resolution of 50 µm. Based on pre-defined boundary markers on the specimen surface, the two fractured halves were digitally realigned using a point-cloud matching technique to reconstruct the fracture topology within the fracture process zone. The spatial mismatch between the reconstructed surfaces was then analyzed to identify crack-space topology, void regions, contact areas, and damage distribution generated during fracture. In addition, a three-dimensional roughness parameter, $Z_{2\text{–}3D}$, defined as the root mean square of directional derivatives of the digital morphology, was calculated to quantify the surface complexity and slope variations of the fracture surfaces. The proposed framework enables systematic comparison of fracture morphology and crack-space characteristics among concretes with different water-to-binder ratios. By linking fracture-surface features with mixture design parameters, the method provides new insights into how water-to-binder ratio influences fracture behavior, mesostructured heterogeneity, and internal damage evolution in cementitious materials.

Abstract #3943

Neutron and gamma irradiation effects on calcium silicate deuterate

Hyeonseok Jee; Elena Tajuelo Rodriguez; Paula C Bran Anleu; Yann Le Pape; and Nishant Garg, University of Illinois Urbana-Champaign, Urbana, IL; Oak Ridge National Laboratory, Oak Ridge, TN

Abstract Text:

Concrete biological shields in nuclear power plants should maintain integrity under prolonged neutron and gamma irradiation, yet the response of the C-S-H binder remains poorly understood. In this study, deuterated C-S-H analogs (C-S-D) with Ca/Si ratios of 0.75 and 1.33 were irradiated for approximately two years to an estimated neutron dose of 1.22 × 10^{19} n/cm^2 (E > 0.1 MeV) and a gamma dose of 1.02 GGy. Thermogravimetric analysis showed that irradiation caused additional water loss for Ca/Si = 0.75, whereas for Ca/Si = 1.33 the heated control and irradiated sample showed similar water loss. Neutron total scattering and Pair Distribution Function (PDF) analysis showed reduced D–O correlation peak intensity near 0.95 Å and decreased Si–Si correlation near 3.1 Å upon heating and irradiation, indicating dehydration and silicate depolymerization. These changes were more pronounced at lower Ca/Si, demonstrating a composition-dependent structural response under gamma- and neutron-irradiation. Overall, we demonstrate how PDF analysis can be a potentially insightful tool in understanding atomic-scale irradiation damage.

Abstract #3945

Admixture-LC3 interactions: Linking nano/microstructure to admixture-modified performance in limestone calcined clay cements

Enzo Amah; Johannes Leisen; Thomas C. Fitzgibbons; Angus P. Wilkinson; and Kimberly E. Kurtis, Georgia Institute of Technology, Atlanta, GA; Dow, Inc., Lake Jackson, TX

Abstract Text:

Limestone calcined clay cements (LC^3) continue to gain global attention for their ability to achieve comparable performance to Portland cement systems while substantially reducing global warming potential. As adoption increases, there is a growing need to understand how chemical admixtures interact with LC^3's distinct hydration reactions and evolving multi-scale structure. In particular, alkanolamines and cellulose ethers are of interest because of their potential to selectively modify early-age reactivity, microstructural development, rheology, and durability-related properties in ways that differ from their behavior in conventional binders.

At the same time, the cement community is shifting from prescriptive specifications toward performance-based frameworks, increasing the urgency of establishing mechanistic linkages between nano-/micro-structural evolution and macroscopic performance. Achieving this understanding is essential for identifying admixture strategies capable of delivering application-specific performance enhancements in LC^3 systems.

This research investigates the influence of three alkanolamines and three hydroxyethyl methyl cellulose (HEMC) admixtures on the nano- and micro-structural development of LC^3 binders at early and later ages. A multi-modal experimental approach is being employed to characterize how these admixtures influence reaction processes, phase assemblage, and physical structure, with the goal of establishing structure–property relationships relevant to performance. The study aims to provide insights that can guide the rational design and optimization of admixture-LC^3 combinations for targeted improvements in mechanical, transport, and rheological behavior, supporting the broader integration of LC^3 into performance-based cementitious systems.

Abstract #3947

Large language model-enabled automated data extraction for concrete materials informatics

Zhanzhao Li; Kengran Yang; Qiyao He; and Kai Gong, Rice University, Houston, TX

Abstract Text:

Data-driven modeling has significant potential to accelerate the design and optimization of cementitious materials, yet its full potential remains constrained by the scarcity of large, high-quality, and accessible datasets. Here, we introduce a generalizable large language model (LLM)-powered pipeline for automated extraction and structuring of composition–process–property information from cement and concrete literature. The pipeline exhibits robust performance across a broad range of LLMs and achieves an F_1 score of up to 0.97 for extracting key materials attributes. Within one-hour automated processing, this pipeline extracts nearly 9,000 high-quality records with over 100 attributes screened from more than 27,000 publications, enabling the construction of the largest open laboratory database for blended cement concrete. Machine learning analyses underscore the importance of large, diverse, and information-rich datasets for enhancing both in-distribution accuracy and out-of-distribution generalization to unseen materials. By substantially reducing manual data curation efforts, the proposed framework enables scalable data infrastructure development for concrete materials informatics and supports data-driven design of next-generation cementitious materials.

Abstract #3950

Impact of SCM quality on uhpc performance: A sensitivity analysis via ppf and UR^2

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

Abstract Text:

The growing demand for next-generation infrastructure has positioned Ultra-High-Performance Concrete (UHPC) as a transformative material in the U.S. construction sector. However, its widespread adoption remains limited due to the dependence on proprietary formulations, which are costly and often require specialized mixing equipment. This study presents a scalable strategy for developing non-proprietary, cost-effective UHPC mixtures by optimizing particle packing and incorporating locally available materials. A range of supplementary cementitious materials (SCMs) sourced locally from Illinois were systematically evaluated through sensitivity analyses to assess their influence on mixing behavior, fresh properties, mechanical performance, and durability of UHPC. To quantify the chemical reactivity of these SCMs, the

7-day R^3 bound-water test was conducted along with the 5-min Ultra-Rapid Reactivity (UR^2) test. The physical effects of the SCMs were assessed via the Particle Packing Factor (PPF) to evaluate the role of fine-particle packing in optimizing UHPC matrix density. The findings provide insights into how variations in chemical composition and particle size influence UHPC performance, supporting the development of locally sourced, non-proprietary UHPC mixtures suitable for large-scale infrastructure applications.

Abstract #3957

Quantifying ye’elimite-ettringite evolution in belitic calcium sulfoaluminate cement from SEM and raman imaging

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Abstract Text:

Belitic calcium sulfoaluminate (BCSA) cement is a complex system in which the primary phase, ye’elimite, hydrates in the presence of a sulfate source to form ettringite. Raman imaging has been identified as a potential tool for quantifying anhydrous cement phases; however, its application to hydrated BCSA systems remains limited. In this study, we extend the use of Raman imaging to analyze the hydrated phase assemblages of belitic calcium sulfoaluminate cement pastes. A key challenge in the Raman characterization of calcium sulfoaluminate cement is that the main sulfate Raman peaks of ye’elimite and ettringite occur at very similar Raman shifts (~985–995 cm^{-1}), which hampers clear phase discrimination and quantification in hydrated BCSA systems. Here, we demonstrate the classification of ye’elimite and ettringite in BCSA cement using Raman spectroscopy in combination with scanning electron microscopy. Preliminary results indicate that the OH band at ~3640 cm^{-1} provides a reliable basis for distinguishing ettringite from ye’elimite. Based on this approach, reasonably accurate and reliable quantification of ye’elimite and ettringite can be achieved. Overall, we report that combining SEM + Raman imaging on the same sample areas allows comprehensive characterization of complex systems.

Abstract #3958

Impact of calcination time on dehydroxylation and morphological evolution of kaolinite via in-situ TEM

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

Abstract Text:

Calcined clays are emerging supplementary cementitious materials, and achieving optimal pozzolanic reactivity requires precise control of calcination conditions to transform kaolinite into highly reactive metakaolin. Although temperature-driven transformation is well established, little is known about how calcination time governs dehydroxylation and particle-scale morphology. Using in-situ transmission electron microscopy with a live heating stage, we show that kaolinite particles undergo time-dependent structural changes during dehydroxylation, including ~15 nm layer thinning and 2–5% area reduction, while complete transformation is tracked directly from electron diffraction patterns. Transformation kinetics correlate strongly with pozzolanic reactivity measured by 7-day R3 testing, with cumulative heat increasing from 850 to 950 J g^{-1} before saturation beyond ~40 min calcination. These results suggest that calcination time not only determines dehydroxylation extent but also drives particle-scale morphological changes which directly influence reactivity. Our findings link transformation kinetics to reactivity and provide a basis for optimizing calcination to produce highly reactive metakaolin.

Abstract #3967

Understanding the influence of ash-to-char ratio of wood-based biochar on the performance of carbon-negative cementitious composites

Nishad Ahmed; Faarzana Mustari Nishat; Kumaran Coopamootoo; Dhrubajouti Karmakar; Sudipto Sarkar; and Warda Ashraf, University of Texas at Arlington, Arlington, TX

Abstract Text:

Biochar produced from biomass pyrolysis is rapidly gaining attention as a sustainable additive for cementitious composites, primarily due to its high carbon sequestration capacity. However, the performance of biochar also depends on the ash-to-char ratio, which varies with feedstock types and pyrolysis conditions. This study investigates how variations in the ash content of wood-derived biochar influence the rheological, mechanical, and durability performance of cementitious composites. Two wood-based biochar were produced by using different nitrogen purging rates during the pyrolysis process. A lower nitrogen flow produced high-ash biochar, mainly containing calcium (~50 wt%), while low-ash biochar exhibited higher silica content (~50 wt%). All paste and mortar samples were prepared by replacing 30% of IL cement with biochar. The mechanical and microstructural properties of biochar incorporated samples were monitored after 7- and 28-days of sealed curing. The experimental results revealed that high-ash biochar exhibited approximately 40% lower moisture absorption capacity than the low-ash biochar, which increased the effective free water in the system and significantly reduced the static yield stress by approximately 90%. Furthermore, the high-ash biochar mixture achieved about 35% higher compressive strength after 7-days of sealed curing and 20% lower autogenous shrinkage compared to the low-ash biochar batch due to the smaller reduction in the effective water-to-binder ratio, which limited internal relative humidity drop and capillary pressure development. Life cycle assessment (LCA) indicated that replacing 30% of cement with biochar reduced the global warming potential (GWP) by up to 105% compared to the control batch. Overall, the results demonstrate that biochar with higher ash content can improve compatibility with cementitious systems by mitigating commonly reported adverse effects of biochar incorporation.

Abstract #3968

Microstructural transformations in carbonated β-C_2s and wollastonite exposed to alkaline solutions

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

Abstract Text:

This study investigates the durability and microstructure evolution of carbonated calcium silicate binders exposed to alkaline environments. Two calcium silicate binders – laboratory-synthesized β-C_2S and commercially available wollastonite were examined for this research. Paste samples were prepared using tap water and subjected to accelerated carbonation curing for 7 days at 75 % relative humidity with 20 % CO_2 purging. Carbonation was conducted at 25 °C for β-C_2S and 55 °C for wollastonite. After the carbonation curing, the samples were submerged for upto 90 days in distilled water and three alkaline solutions: $Ca(OH)_2$ (supersaturated), $Mg(OH)_2$ (supersaturated), and NaOH (pH = 13). The mechanical performance was measured by compressive strength testing and nanoindentation, while microstructural changes were characterized using thermogravimetric analysis (TGA), Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), mercury intrusion porosimetry (MIP), and scanning electron microscopy (SEM). After 7 days of carbonation, β-C_2S exhibited approximately 23% more strength than wollastonite due to concurrent hydration and carbonation reactions. In contrast, wollastonite sequestered approximately 40% more CO_2 compared to β-C_2S samples owing to its higher calcium content and showed differences in carbonate polymorphs. Initial exposure to alkaline environments resulted in a reduction of 17-28% strength in β-C_2S samples, depending on the alkaline solutions, within 7 days, whereas the reductions were 19-31% for wollastonite samples. However, gradual strength recovery was observed with longer exposure durations. Samples exposed to $Ca(OH)_2$ solution recovered their original strength within 56 days for both binders, which is attributed to the formation of additional C-S-H. Both binder systems also exhibited a decrease in silicate polymerization, indicating the incorporation of cation in polymerized silica gel, forming either C-S-H, M-S-H, or N-S-H depending on the cations present in the alkaline solution.

Abstract #3970

Recyclability and CO_2 mineralization potential of biochar-amended cementitious concrete

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

Abstract Text:

Biochar has emerged as a promising additive in cementitious materials because of its carbon-sequestering capability and potential to reduce the carbon footprint of ordinary Portland cement (OPC)-based systems. However, to assess the role of biochar in sustainability, how such additives influence the end-of-life stage or recyclability of concrete also needs to be considered. Considering the relative softness of biochar particles compared to aggregates, it is expected that during concrete crushing during recycling, biochar will become a part of the fine fractions, mixed with cement-paste. Therefore, this study evaluates the upcycling potential of biochar-modified cement paste as future filler or supplementary cementitious materials. Two pathways designed for CO_2 capture and material recovery were investigated: a multi-step pH-swing carbon mineralization method and a direct wet carbonation method. Both approaches were assessed in terms of calcium extraction, CO_2 sequestration, recovery of previously incorporated biochar, and the characterizations of the resulting solid residues through XRD, TGA, SEM, and R3. Results showed that biochar remained recoverable in both routes, with up to 61% recovery achieved in the multi-step method. Furthermore, the presence of biochar did not significantly affect the characteristics of the recovered residues at each processing stage. The multi-step route enabled nearly complete calcium extraction (99%), followed by re-carbonation into a high-purity calcium carbonate, with a CaO utilization efficiency up to 79% and a CO_2 sequestration capacity up to 250 mg g^{-1}. Additionally, silica-rich residual solids were generated, indicating potential for reuse as supplementary cementitious materials. The direct wet carbonation route also demonstrated promising performance, achieving a CO_2 sequestration capacity of up to 146 mg g^{-1} with CaO utilization efficiencies of up to 42%, while offering a simpler and less time-intensive processing pathway. These findings demonstrate a feasible strategy for integrating recyclability, CO_2 mineralization, and material circularity in biochar-amended cement systems.

Abstract #3971

Gaussian process regression for predicting rheological behavior of cement slurries with calcined clays

Sudipto Sarkar; Amrita Basak; and Warda Ashraf, The University of Texas at Arlington, Arlington, TX; The Pennsylvania State University, University Park, University Park, PA

Abstract Text:

Fresh rheological properties of cement paste are governed by multiple interacting factors, including material composition, particle characteristics, water availability, and the presence of supplementary cementitious materials (SCMs). Although machine learning (ML) is increasingly used to predict such properties, many studies rely on large datasets, which reduces reliability and interpretability when experimental data are limited. In this study, Gaussian Process (GP) regression is employed to investigate predictive performance and quantify uncertainties in a low-data regime using an experimental dataset of 112 tests of cement pastes incorporating 9 different types of calcined clay (CC) as SCMs. Clay types included pure kaolinite, montmorillonite, and illite, and impure clays with different proportions of clay minerals along with quartz. The objective is to identify which physicochemical properties of CC most influence rheology (yield stress and viscosity) and to predict the rheological behavior of unseen clay types using these descriptors. Principal Component Analysis (PCA) and SHapley Additive exPlanations (SHAP) analysis show that water absorption and total heat release of CC from R^3 test are most influential descriptive parameters to predict output. This approach enables descriptor-based transfer learning, where knowledge from known clay systems is generalized to compositionally different clays. GP regression is selected for its suitability in small datasets, enabling uncertainty-aware predictions. Kernel-based similarity and Automatic Relevance Determination (ARD) are used to capture smooth material trends and assess the importance of input parameters. The predictive performance of the GP model is compared

with Artificial Neural Network (ANN), Decision Tree (DT), and Random Forest (RF), where GP shows the best accuracy (MAE = 9.65, RMSE = 15.15) providing uncertainty-aware and physically interpretable predictions for rheology in cementitious systems.

Abstract #3972

Optimization of low-paste volume concrete – integrating Compressible Packing Model (CPM) with particle filler effect thresholds for enhanced sustainability

Marcus Cheung, University of California, Berkeley

Abstract Text:
The production of Portland cement remains a primary contributor to the carbon footprint of the construction industry. This research investigates the development of low-paste volume concrete as a viable strategy to reduce the clinker factor without compromising rheological or mechanical performance. The methodology follows a two-stage optimization process: first, the determination of the maximum particle size threshold for the "filler effect" to take place, and second, the maximization skeleton density through the Compressible Packing Model (CPM). The "filler effect" – characterized by the provision of additional nucleation sites for calcium silicate hydrate – was evaluated via Isothermal Calorimetry. By monitoring the heat of hydration and the acceleration of the peak heat flow, the degree of hydration for various filler sizes was quantified. The findings indicate that particles below a specific micron threshold significantly accelerate the hydration kinetics, whereas above which point, particles behave as a purely physical void-filler. This threshold informs the optimal ratio of cement, filler, and aggregates to achieve a highperformance matrix with a minimized binder content. The packing density of the skeleton density (coarse aggregate, fine aggregate, and filler particle) was optimized using the CPM to minimize the inter-particle void ratio, and hence the volume of cementitious paste required to ensure workability and strength. The resulting paste content was limited to 150 kg/m3, representing a significant reduction from conventional mixtures. Performance metrics such as compressive strength, workability, volumetric stability, pumpability, and durability properties all meet ASTM standards, comparable to conventional concrete. In terms of sustainability, a carbon footprint of 200 kgCO2e/m3 was achieved. The integration of the CPM for void reduction and the strategic selection of filler sizes based on hydration kinetics allows for the production of a durable, flowable, and eco-friendly concrete that meets the stringent requirements of modern structural engineering.

Abstract #3973

Modeling of hydration kinetics and viscoelastic properties of Portland limestone cement blended with biochar from downdraft gasification

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

Abstract Text:
The rapid adoption of Portland limestone cement (PLC) in the United States as a lower-carbon binder necessitates an improved understanding of how emerging additives influence hydration and early-age performance. This study evaluates the impact of incorporating biochar (1–10 wt.% replacement) on the hydration kinetics and viscoelastic evolution of PLC pastes. Isothermal calorimetry reveals systematic modifications in heat flow, including reduced peak intensity and shifts in characteristic hydration times with increasing biochar content. Hydration behavior is modeled using the Krstulović–Dabić framework coupled with the Knudsen equation, enabling quantification of nucleation and growth, phase boundary, and diffusion-controlled regimes. Results indicate that biochar alters reaction pathways and accelerates transitions (from α=22 for PLC to $\alpha\leq$20 for blends) toward the rate-limiting diffusion-controlled stage. Concurrent rheological measurements show strong coupling between hydration and structure development, with early-age increases in storage modulus (G') driven by flocculation and later evolution governed by hydration. Biochar increased the critical strain from 0.01% to about 0.03%, indicating an enhanced resistance to structural breakdown and a more robust particle network capable of sustaining

larger deformations before yielding. These findings establish a mechanistic link between hydration processes and viscoelastic response, providing guidance for optimizing biochar–PLC systems for sustainable construction.

Abstract #3974

Experimental and computational investigation of rheological behavior of ultra-high-performance concrete enhanced by cellulose nanofibers

Xiaoli Xiong; Rongze Hu; Kamal Khayat; and **Chengcheng Tao**, Purdue University, West Lafayette, IN; Missouri University of Science and Technology

Abstract Text:

Nanoadditives have long been used to modify the fresh and hardened properties of ultra-high-performance concrete (UHPC). In this context, cellulose nanofibers (CNFs), typically derived from waste paper through chemical-free processes, represent a renewable and sustainable class of nanomaterials. This study investigates the rheological behavior of fresh UHPC incorporating CNFs, as well as the microstructural development through hydration analysis and backscattered scanning electron microscopy–based porosity characterization. Furthermore, as the numerical extensions, computational fluid dynamics (CFD) modeling was employed to simulate the extrusion behavior of fresh UHPC in 3D printing and to evaluate the permeability of hardened UHPC with CNFs. The results demonstrate that CNFs significantly increase the yield stress, shear-thinning behavior, and thixotropy of UHPC, indicating ideal 3D printing ability. Meanwhile, CNFs contribute to microstructural densification in hardened UHPC, thereby reducing porosity and permeability, enhancing mechanical performance, and ultimately improving durability.

Abstract #3975

Development of calcined clay/calcium sulfate blends for robust performance of LC3 concrete

Denise A. Silva and Paula Bran Anleu, Oak Ridge National Laboratory, Oak Ridge, TN

Abstract Text:

This report documents the development of robust blends of calcined clays (CCs) with calcium sulfate (gypsum) for application in limestone calcined clay cement (LC3) systems. The U.S. cement industry faces supply chain constraints and high energy intensity, motivating the need for alternative supplementary cementitious materials. Calcined clays are abundant and highly reactive when properly processed, but their variable physical and chemical characteristics can negatively impact hydration balance, rheology, and admixture demand in LC3 concretes. To address this, five calcined clays, two Portland cements, ground limestone, gypsum, and a polycarboxylate dispersant were procured. Isothermal calorimetry and mini-cone flow tests were used to determine sulfate and dispersant demand. Results show that the addition of approximately 6.7% gypsum, relative to the calcined clay weight, consistently balanced sulfate consumption across the LC3 systems studied. Dispersant demand, however, varied significantly with clay source, demonstrating the need for tailored admixture strategies. These findings confirm that supplying CC–gypsum blends directly to concrete producers is a viable approach to overcoming current manufacturing constraints, enabling reliable fresh and hardened performance of LC3 concretes, and supporting broader adoption of calcined clays in the U.S. market.

Abstract #3976

Elastoplastic behaviors of mortar and olivine rock: A triaxial study

Geng Niu and Laura E. Dalton, Duke University, Durham, NC

Abstract Text:

Understanding the fundamental elastoplastic and damage behaviors of cementitious materials and reactive rocks under complex multiaxial stress states is critical for evaluating their structural integrity and potential in Carbon Capture, Utilization, and Storage (CCUS) applications. This study investigates the macroscopic mechanical response of these materials using an Environmental Triaxial Automated System (ETAS). Displacement-controlled triaxial tests with cyclic load-unload paths are conducted on carbonated and uncarbonated mortar specimens, alongside cored olivine stone, under varying confining stresses. A dual-modulus analysis is utilized to capture initial compaction effects and quantify progressive damage evolution, tracking stiffness degradation and plastic strain accumulation throughout the pre- and post-peak stages. Furthermore, the confinement-induced transition from brittle failure to ductile flow is characterized, yielding precise Mohr-Coulomb failure envelopes. Ultimately, these macroscopic damage parameters establish an essential mechanical baseline. These data are vital for calibrating fully coupled physics-based models to predict reaction-induced strength changes, supporting the safe deployment of carbon-negative materials in large-scale infrastructure.

Abstract #3977

Microstructural evaluation of solid waste supplementary cementitious materials for enhanced concrete thermal energy storage systems

Soniya Tiwari and Laura E. Dalton, Duke University, Durham, NC

Abstract Text:

Concrete thermal energy storage (CTES) is a promising strategy to extend the service life of existing energy infrastructure at coal-fired power plants and produce electricity[1]. Prior studies have demonstrated the feasibility of concrete-based thermal energy storage and high-temperature CTES operation, although these systems still rely predominantly on Ordinary Portland Cement (OPC) [1–4], in thisstudy we investigate the use of solid waste-derived supplementary cementitious materials (SCMs) in high-temperature CTES systems including coal combustion ash and biochar at 0 % and 20 % replacement levels to determine how SCM incorporation influences thermal durability and mechanical performance combined with aggregates with higher thermal conductivity including olivine and basalts. The experimental program combines thermal cycling up to 700 °C, compressive strength testing, thermogravimetric analysis, and X-ray micro-computed tomography (micro-CT). X-ray micro-CT is used to characterize microstructural evolution due to thermal exposure (Figure 1), enabling analysis of pore development, crack initiation, and fracture propagation. Quantitative microstructural metrics are then related to bulk mechanical and thermal performance. This work aims to establish a material design framework for lower-carbon CTES composites with improved thermal durability and energy storage potential.

Abstract #3978

Alkali fusion–activated copper tailings as supplementary cementitious materials: reactivity, hydration kinetics, and microstructural evolution

Jiankai Xie; Xiang Zhao; and Qingli Dai, Michigan Technological University, Houghton, US

Abstract Text:

This study investigates the activation of copper mine tailings as supplementary cementitious materials (SCMs) through alkali-fusion treatment to enhance their pozzolanic reactivity and performance in cementitious systems. Copper tailings are rich in aluminosilicate phases but exhibit inherently low reactivity due to their stable crystalline mineralogy, primarily composed of albite and diopside. To overcome this limitation, alkali fusion using NaOH and Na_2CO_3 was conducted at 800 °C with varying dosages to induce structural depolymerization and amorphization. The effects of alkali activation on mineralogical transformation, dissolution behavior, hydration kinetics, and microstructural evolution were systematically evaluated using X-ray diffraction (XRD), scanning electron microscopy (SEM), Frattini testing, R3 calorimetry, thermogravimetric analysis (TGA), and pore solution chemistry analysis. Results indicate that alkali fusion significantly alters the crystalline structure of tailings, generating reactive amorphous sodium aluminosilicate phases. Among the tested conditions, NaOH activation at 50% dosage (CN50) exhibited the highest pozzolanic reactivity, characterized by enhanced calcium hydroxide consumption, increased cumulative heat release, and higher bound water content. When incorporated into cement systems, the activated tailings accelerated early hydration kinetics, promoted the formation of secondary C–A–S–H and carbonate-bearing AFm phases, and refined the pore structure. Microstructural analysis confirmed substantial densification associated with increased amorphous phase content and enhanced aluminosilicate dissolution. Mortars containing 10–20% alkali-fused tailings demonstrated improved mechanical performance, achieving up to 5–15% higher compressive strength at 28 days compared to the control mixture. Overall, this study demonstrates that alkali-fusion activation effectively transforms low-reactivity copper tailings into high-performance SCMs. The findings establish a clear relationship between alkali-induced amorphization, dissolution kinetics, and hydration behavior, providing a viable pathway for sustainable utilization of mine tailings in low-carbon cementitious materials.

Abstract #3979

Performance and carbon reduction of binary and ternary concrete systems with slag cement and fly ash

Xiang Zhao; Jiankai Xie; and Qingli Dai, Michigan Technological University, Houghton, US

Abstract Text:

Reducing the carbon footprint of cement based materials is essential for achieving sustainable infrastructure development. This study presents a systematic investigation of low-carbon binary and ternary concrete systems incorporating high-volume replacements of slag cement and Class C and Class F fly ash as supplementary cementitious materials (SCMs). Ten mixtures were designed with SCM replacement levels ranging from 30% to 70%, including an ordinary Portland cement (OPC) control. The mixtures were evaluated in terms of early-age fresh properties, mechanical performance, durability characteristics, and cradle-to-gate carbon emissions. The results indicate that binary slag systems enhance mechanical performance, achieving approximately 15% higher 28-day compressive strength than the OPC control due to continued hydration reactions. Ternary systems exhibit slower early-age strength development; however, improvements emerge at later ages. Mixtures containing Class C fly ash demonstrate superior long-term strength, with increases of 11–15% at 180 days, attributed to their higher calcium content and partial self-cementing behavior. In contrast, ternary mixtures incorporating Class F fly ash show reduced early strength but provide durability benefits, including 25–40% reductions in drying shrinkage. In addition, binary and Class C ternary mixtures exhibit higher surface resistivity, indicating reduced ionic transport and improved matrix densification. All SCM-based systems maintain adequate freeze–thaw resistance, with minimal degradation after extended cyclic exposure. These improvements are governed by slag hydration and fly ash pozzolanic reactions, which refine the pore structure and enhance matrix continuity.

From an environmental perspective, replacing OPC with SCMs lowers embodied carbon emissions. Depending on the replacement level, reductions of 26–63% are achieved, demonstrating a clear inverse relationship between clinker content and carbon impact. In addition, a transfer learning-based Random Forest model was developed to predict compressive strength in high-volume SCM systems. The model achieved a coefficient of determination (R^2) of 0.961 and a root mean square error of 1.87 MPa, demonstrating its ability to capture complex nonlinear relationships between mixture composition and strength development. Overall, an optimized ternary mixture containing 50% OPC, 30% slag cement, and 20% Class C fly ash provides the best balance between mechanical performance, durability, and sustainability, delivering approximately 11% higher 180-day compressive strength than the control while reducing drying shrinkage by 20–35% and lowering carbon emissions by approximately 45%.

Abstract #3980

Reactive vaterite derived from recycled concrete powder to enhance reactivity and performance of LC3 containing low-grade calcined clays

Jiankai Xie; Xiang Zhao; and Qingli Dai, Michigan Technological University, Houghton, US

Abstract Text:

Reducing the carbon footprint of cementitious materials is critical for sustainable infrastructure development. Limestone calcined clay cement (LC3) offers a promising pathway by significantly lowering clinker content; however, its performance is highly dependent on the reactivity of calcined clays. Low- and medium-grade clays typically exhibit limited alumina release, leading to delayed hydration and reduced early-age strength. This study investigates the use of reactive vaterite, derived from recycled concrete powder (RCP), as an alternative carbonate source to enhance the performance of LC3 systems. The objective is to evaluate whether vaterite, with its higher solubility compared to conventional limestone, can improve carbonate availability and promote earlier aluminate–carbonate reactions, thereby enhancing alumina utilization efficiency in low-reactivity clay systems. A comparative experimental program was conducted using ordinary Portland cement (OPC), conventional LC3, and vaterite calcined clay cement (VC3) with identical binder compositions except for the carbonate phase. Hydration kinetics were assessed using calorimetry, while phase assemblage evolution was characterized by X-ray diffraction (XRD) and thermogravimetric analysis (TGA). Microstructural development was evaluated through scanning electron microscopy (SEM) and pore structure analysis. Mechanical performance was determined through compressive strength testing at different ages. Results indicate that vaterite accelerates early hydration, shortens the induction period, and increases early heat release. VC3 systems exhibit earlier formation of hemicarboaluminate and increased monocarboaluminate at later ages. Microstructural analysis reveals refined pore structure, contributing to improved strength development. Overall, the incorporation of RCP-derived vaterite enhances hydration efficiency and mechanical performance in LC3 systems with low-grade clays. This approach provides a dual benefit of performance improvement and carbon utilization, supporting the development of next-generation low-carbon cementitious materials.

Abstract #3981

Exploring ReefCycle biocement as a sustainable supplementary cementitious material

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Abstract Text:

The negative environmental impacts of cement production are well known, accounting for nearly 8% of global carbon emissions annually. The cement clinkering process is energy intensive, often relying on fossil fuels to achieve the necessary high temperatures, but the chemical reaction involved in clinker production itself releases CO2 as a byproduct, accounting for the majority of carbon emissions in cement. Supplementary Cementitious Materials (SCMs) offer an emerging solution to this issue by replacing and reducing the amount of Portland cement in a given mixture. This study explores enzyme-mediated production of biocement as an SCM, through a process called Accelerated Enzyme-Induced Calcite Precipitation (AEICP) involving plant-derived enzymes. This AEICP process has been developed and tested in coordination with ReefCycle, a start-up company initially interested in producing calcite for coral reef repair. The investigation considers mortar samples with varying biocement replacement levels, up to 50%, comparing in situ hydration, compressive strength, and crack propagation using time-resolved X-ray micro-computed tomography. These findings support the use of alternative plant-derived SCMs in both structural and non-structural applications.

Abstract #3982

Cement-based batteries with biochar-tuned microporous networks: A solution to infrastructure-integrated energy storage

Zhiliang Zhou; Jialuo He; Yong Deng; and **Xianming Shi**, University of Miami, Coral Gables, FL; Chinese Academy of Sciences, Qingdao, China; Widener University, Chester, PA; Washington State University, Pullman, WA; South China University of Technology, Guangzhou, China

Abstract Text:

Cement-based batteries offer a promising pathway for self-powered sensing in remote or infrastructure-limited environments; however, their real-world deployment remains limited due to persistent challenges of early-stage energy decay and long-term instability. This study aims to address this gap by developing a novel cement-based battery system integrating a discrete Zn-embedded cement-based anode (DZCA) with internal steel reinforcement as the cathode. A pore-structure optimization strategy combining foaming agents and porous biochar particles (BCPs) within the anode encapsulating matrix was employed to overcome the electrochemical limitations of cement batteries. The foaming-agent–generated macropores enhanced ionic conductivity and facilitated anodic-product transport, while BCPs acted as internal electrolyte reservoirs capable of storing and gradually releasing alkaline solution at the Zn–matrix interface. Multiple techniques (SEM-ImageJ, BET, and micro-CT) were used to evaluate the pore-structure characteristics of the encapsulating matrix, and a 20-week wet/dry discharge test under chloride-rich conditions was performed to assess the long-term applicability of the prepared cement-based batteries. The results showed that the BCP incorporation markedly regulated the early-stage anode activation and sustained the superior long-term performance of cement-based batteries, which is attributable to the electrolyte-buffering capability of BCPs. EIS, SEM-EDS, and resistivity measurements further verified that slow electrolyte release from BCPs maintained pore-solution continuity, stabilized local alkalinity, and sustained charge-transfer processes. Finally, the prepared batteries with mean pore sizes between 7.5 and 29 µm demonstrated superior energy retention and electrochemical durability under the tested conditions, indicating a critical pore-size window and providing a microstructural design guideline for durable, infrastructure-integrated cement-based energy storage systems.

Abstract #3983

Analysis of various lunar geopolymers mixed and cured on the International Space Station

Adam Johnson; Louise Littles; Aleksandra Radlińska; and Sven Bilén, The Pennsylvania State University, College Park, PA; NASA Marshall Space Flight Center, Hunstville, AL

Abstract Text:

The research outlined in this presentation investigates the use of various lunar regolith simulants in lunar geopolymers mixed and cured on the International Space Station (ISS). The study was conducted to evaluate the effects of gravity on the microstructure of heat-cured alkali-activated materials and to develop materials for the construction of long-term infrastructure on the lunar surface via in-situ resource utilization (ISRU). ISRU reduces the cost and mass of payloads related to lunar construction and is the only viable solution for extraterrestrial infrastructure development.

Twelve samples of lunar regolith simulant and a solution composed of sodium hydroxide and sodium silicate were sent to the ISS. The three simulants were OPRH2N, OPRL2N, and JSC-1AF, using only particles less than 53 µm in diameter to increase the reactivity of the simulant. Simulant-to-solution ratios were determined based on workability during mixing. The simulant and solution were sealed in separate compartments of Burst Pouches®, along with 2 additional sealed bags, to prevent leakage. Crew member F-14 conducted testing on the ISS by introducing the solution to the simulant in the Burst Pouch®, mixing the sample with a spatula, and then clamping the specimen in the fresh state to prevent flow inside the Burst Pouch®. These specimens were then placed in a thermos containing sealed drinking water bags heated to 80 °C to cure for 24 hours. The temperature logger maintained continuous temperature tracking and the cured specimens remained in microgravity for at least 28 days. They were returned from the ISS in February 2025. The specimens were then brought to NASA's Marshall Space Flight Center (MSFC) for

further analysis. Material characterization consisted of conducting Micro-CT tests of entire samples in their sealed apparatus to a resolution of 25µm. 2D image slices were saved in each orthogonal direction of each specimen at a 0.03 mm step size from the 3D model for future modeling. Representative samples from each specimen were then used to perform helium gas pycnometery and mercury intrusion porosimetry (MIP). Helium gas pycnometry samples were then impregnated with epoxy for SEM imaging, EDS, and nanoindentation. Due to the samples' non-uniform shape (after being cured in a pouch), traditional compression and tensile strength testing could not be performed. Nanoindentation, instead, will be conducted at Clarkson University to determine the microhardness and the reduced elastic modulus. Mechanochemical modeling can be done by correlating microhardness and reduced modulus values to C-A-S-H and N-A-S-H phases. Ground sample analysis is currently ongoing. This study provides further insight into alkali-activated materials and their viability as a lunar construction material with ISRU.

Abstract #3984

Insights into the effect of the sulfate-to-alkali ratio on the C3A polymorphism of lab-synthesized Portland clinkers

Ivo de Castro Carvalho; José da Silva Andrade Neto; Paulo Matos; **Ana Paula Kirchheim**, Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil; Santa Catarina State University (UDESC), Laguna, Brazil

Abstract Text:

This study investigates the effects of sulfate-to-alkali ratio and alkali type on C_3A polymorphism in laboratory-synthesized Portland clinkers. Clinkers were produced using controlled raw meal compositions with external doping of sulfates and alkalis (Na_2O and K_2O). X-ray diffraction combined with Rietveld quantitative phase analysis (RQPA) was employed to determine the phase assemblage and the distribution of C_3A polymorphs. Results show that increasing the sulfate-to-alkali ratio favors the stabilization of cubic C_3A in a moderate correlation strength. However, significant differences were observed depending on alkali type. Sodium strongly promoted orthorhombic C_3A formation, whereas potassium showed a much weaker effect, even at similar sulfate-to-alkali ratios. These findings indicate that alkali type plays a more decisive role than the sulfate/alkali ratio alone when external alkali incorporation is considered. The results provide new insights into clinker phase formation under varying chemical conditions, highlighting the importance of distinguishing between Na and K effects in laboratory synthesis environments.

Abstract #3985

Uncertainty-aware bayesian multi-objective optimization for sustainable concrete mix design

Xianming Shi and **Mayaz Uddin Gazi**, University of Miami, Coral Gables, FL

Abstract Text:

Developing sustainable concrete mixes requires balancing maximization of compressive strength, environmental effects, and the cost of the material. However, these are often (but not always) mutually contradictory goals. Current machine learning techniques in concrete mix design mainly deal with single-objective prediction, rarely quantify the uncertainty, and seldom do a real multi-objective trade-off analysis with Pareto front generation. This study develops a multi-objective Bayesian optimization (MOBO) framework that couples Gaussian Process (GP) surrogate models with the qLogNEHVI acquisition function. qLogNEHVI is the latest noise-robust, numerically stable hypervolume-based acquisition function in the BoTorch library. The framework simultaneously maximizes compressive strength while

minimizing global warming potential (GWP) and material cost.
Three independent GP surrogates were built using Matérn 5/2 kernels with automatic relevance determination (ARD). The models were trained on 1,030 concrete mix records. Five-fold cross-validation result for R^2 values of 0.915, 0.919, and 0.891 for strength, GWP, and cost, respectively. The MOBO engine ran 20 iterations with a batch size of q = 3. It achieved a 16.6% gain in hypervolume over the initial dataset and identified 23 Pareto-optimal mixes. These mixes span 40–117 MPa in strength, 100–430 kg CO_2e/m^3 in GWP, and 40–107 USD/m^3 in cost.
The ARD lengthscale analysis demonstrate physically meaningful patterns: water content and curing age most strongly influenced strength, whereas cement content dominated both GWP and cost. Based on the same experiment design qLogNEHVI outperformed random sampling by approximately 40% in hypervolume. Every Pareto-optimal solution includes 95% confidence intervals, allowing engineers to make decisions based on quantified uncertainty rather than single-point estimates. This validated framework is designed for extension to biochar–seawater–sea sand mortar systems with additional objectives including workability and bulk resistivity, using closed-loop active learning driven by laboratory experiments.

Abstract #3996

Insights into the carbonation of industrial slags: Role of Mg and Al

Kumaran Coopamootoo, Farzana Mustari Nishat, Warda Ashraf

Abstract Text:

Industrial slags (e.g., granulated blast furnace slags) are mainly composed of reactive calcium-magnesium aluminosilicate glasses. Since similar silicates easily bind CO2, industrial slags represent an abundant opportunity for CO2 sequestration. To pave the way towards this, it is essential to understand the effects of the variable composition of these constituent glasses on carbonation. Here, we synthesize pure glasses by ball-milling molar proportions of CaO, SiO2, Al2O3 and MgO, followed by calcination at 1550oC and quenching in deionized water. The glasses are ground and exposed to CO2. First, we investigated the carbonation of glasses with only CaO, SiO2 and Al2O3 with Al/Si ratios = 0.06 – 0.32 via dry carbonation with water to solid ratio (w/s) of 0.6ml/g and wet carbonation with w/s of 20ml/g, both at 50oC. In our second study, we investigated the effect of Mg/Ca on carbonation of glasses containing CaO, SiO2, Al2O3 and MgO at high and low Al/Si under the wet carbonation setup. The carbonation rate and products were characterized using X-ray diffraction, Fourier transform infrared spectroscopy, nuclear magnetic resonance. scanning electron microscopy, and thermogravimetric analysis; the latter was used to derive the degree of carbonation (DOC) of the carbonated glasses. Our results showed that the two carbonation methods operate differently, and that wet carbonation causes a higher degree of carbonation (DOC) than dry carbonation. We also showed the decreasing carbonation ability of glasses when Al/Si ≥ 0.17, which is due to Al-rich regions requiring charge balancing by Ca2+ and preventing their release. Experimental results further show that increasing Mg/Ca results in a decrease in the glasses' carbonation, with low Al/Si glasses performing better. Furthermore, carbonation products include calcite, aragonite, amorphous CaCO3 and hydrotalcite. Degree of carbonation of Mg-containing glasses was affected by the carbonation products as well.

Abstract #3997

Low-temperature efflorescence-resistant geopolymers from zeolite-metakaolin hybrid precursors

S.K. S. Hossain; Atolo A. Tuinukuafe; Jessica M. Rimsza; **Jeffrey W. Bullard,** Texas A&M University, College Station, TX; Sandia National Laboratories, Albuquerque, NM

Abstract Text:

Traditional metakaolin-based geopolymers often have challenging rheological properties, low early strength gains, and significant efflorescence. We demonstrate that all of these challenges can be largely overcome by incorporating synthetic zeolite Y (ZY) and eggshell-derived calcium oxide (e-CaO) in the formulation. ZY increases aluminosilicate dissolution rates and may provide preferential sites for gel nucleation. The viscosity of the fresh mix can be tuned to some extent by tailoring the proportions of ZY and e-CaO. Adding e-CaO also promotes the formation of some calcium silicate hydrate (C–S–H) gel that both enhances the structural integrity and increases the viscosity at early ages. Combining ZY and e-CaO with metakaolin produces a dense and homogeneous matrix relative to neat metakaolin-derived geopolymers. The hybrid formulations have compressive strengths up to 60% greater than ones with only metakaolin at the same age, and ZY and e-CaO together also greatly decrease or even eliminate efflorescence. Besides these advantages, the hybrid formulation can be easily cured at room temperature, in contrast to geopolymers based on metakaolin alone.

Abstract #3998

Microstructural characteristics of cement paste mixed with cellulose nanocrystal and graphene oxide

Yun-Kyung Lee; Ji-Hyun Kim, Chul-Woo Chung, Pukyong National University, Busan, South Korea

Abstract Text:

This study investigated the microstructural development of cement paste incorporating cellulose nanocrystal (CNC) and graphene oxide (GO), with particular emphasis on the synergistic interaction between the two nanomaterials. CNC and GO suspensions were prepared and their dispersion behavior was evaluated using UV–Vis spectroscopy, dynamic light scattering (DLS), and viscosity measurements. Based on these results, cement pastes containing different combinations of CNC and GO were assessed in terms of rheology, hydration characteristics, pore structures, and compressive strength. The results showed that the interaction between CNC and GO strongly depended on GO concentration. At low GO content, CNC improved GO dispersion, whereas at higher GO content CNC promoted re-agglomeration. This difference in dispersion behavior significantly influenced the hydration and microstructural evolution of cement paste. Among the mixtures investigated, the combination of 0.10 wt.% CNC and 0.05 wt.% GO showed the highest compressive strength, which was 50.98% higher than that of the plain cement paste.

Abstract #3999

Properties of geopolymer paste made of borosilicate glass powder and metakaolin

Gang-Min Noh; Ji-Hyun Kim; Ph.D., Chul-Woo Chung, Pukyong National University, Busan, South Korea

Abstract Text:

This study investigated the properties of geopolymer paste prepared using borosilicate glass powder (BSG) and metakaolin (MK) as binders, focusing on the effects of BSG replacement ratio on rheological behavior, microstructural network formation, and compressive strength development. Geopolymer pastes were fabricated at a fixed binder-to-alkali activator solution weight ratio of 1.5, with sodium silicate-to-sodium hydroxide solution weight ratios of 1.5 and 2.0, and BSG replacement levels of 0, 25, 50, and 75 wt.%. Since BSG-only systems exhibited deformation during air curing, analysis was confined to BSG-MK binary systems, which were moist-cured at 80°C for 2 days and subsequently stored under ambient laboratory conditions (23°C ± 1°C, RH: 60%). X-ray Diffraction, Fourier Transform Infrared Spectroscopy were used to characterize the structure of produced geopolymer. Rheology and compressive strength measurements were followed to investigate the effect caused by BSG replacement on metakaolin based

geopolymer. In this work, the effect caused by partial replacement of MK with BSG will be systematically discussed, making it a promising binder candidate for neutron-shielding applications.

Abstract #4004

Towards carbon-neutral FRP-reinforced biochar engineered cementitious composites slab

Jason S. Houston; Zhigang Zhang; and Xianming Shi, University of Miami, Coral Gables, FL

Abstract Text:

Engineered cementitious composites (ECC) reinforced with polyethylene (PE) fibers exhibit strain-hardening behavior, tight crack-width control, and enhanced durability, making them promising for marine infrastructure applications. In this study, biochar-modified high-strength ECC reinforced with GFRP bars was proposed for sustainable marine deck slabs. The mechanical properties of biochar-modified ECC were investigated, and seven one-way slab specimens with different GFRP reinforcement ratios were tested under four-point bending. The results showed that incorporating biochar at 10 wt.% of cement mass towards the net-zero carbon emission in ECC while maintaining favorable mechanical performance. The tensile strain capacity increased from approximately 2% to 4% without compromising tensile strength, whereas the compressive strength decreased moderately from approximately 80 MPa to 70 MPa. Dense multiple microcracks developed in the tensile zone of the ECC slabs, indicating sustained post-cracking load-carrying capacity due to the fiber-bridging effect. Compared with the unreinforced ECC slab, the ultimate load increased from approximately 15 kN to more than 70 kN with increasing GFRP reinforcement ratio. A clear transition in failure mode was observed with increasing reinforcement ratio. Lightly reinforced slabs failed by GFRP rupture, moderately reinforced slabs exhibited flexural failure, while highly reinforced slabs failed in shear before fully developing their flexural resistance. The results indicate that excessive enhancement of flexural capacity may shift the governing structural mechanism from flexure to shear. This study provides new insights into the design of sustainable GFRP-reinforced ECC marine deck panels.

Abstract #4005

Tuning clay self-assembly for 3D-printing of bio-stabilized earthen construction materials

Yierfan Maierdan; In Kuk Kang; Jae Hong Kim; and Shiho Kawashima, Columbia University, New York, NY; Korea Advanced Institute of Science and Technology, Daejeon, South Korea

Abstract Text:

Natural soils form hierarchical structures through physicochemical self-assembly—a principle that can be harnessed to design sustainable, high-performance building materials. We present a scalable approach that tunes kaolinite self-assembly via controlled chemical environment and guar gum (GG) addition, enhancing strength while retaining 3D printability. Physicochemical, rheological, and mechanical analyses show that pH regulates clay self-assembly by altering particle surface charge, whereas GG restructures networks through polymer bridging. Multiscale characterization reveals that although similar microstructures can develop across compositions when stabilized with sufficient biopolymer at different pH, the pathways leading to their formation differ. Networks are formed primarily through colloidal interactions (van der Waals and electrostatic forces) or induced by biopolymer bridging. Despite appearing structurally similar, biopolymerassembled networks exhibit significantly greater strength—exceeding 110% improvement—compared to those formed through colloidal interactions. These results highlight that the origin of microstructure critically governs performance, introducing a new designing principle for sustainable, printable materials.

Abstract #4006

Multi-carbonation strategy enables carbon-negative concrete infrastructure: An uncertainty-aware life cycle assessment

Zhipeng Li and Xianming Shi, University of Miami, Coral Gables, FL

Abstract Text:

This study investigates a multi-carbonation strategy for biochar-based concrete and its carbon footprint. Pre-carbonated biochar, recycled concrete aggregate (RCA), and simulated concrete wash water were incorporated as partial replacements for Portland limestone cement (PLC), natural aggregate, and mixing water, respectively, to enhance microstructural densification and interfacial bonding performance. Chloride transport behavior was evaluated using rapid chloride migration (RCM) testing, and the obtained diffusion parameters were incorporated into the Life-365 model to predict the service life of concrete under chloride exposure conditions. In addition, a probabilistic carbon assessment framework integrating service-life prediction with Monte Carlo-based uncertainty analysis was developed. The results indicate that the proposed multi-carbonation strategy, through improved biochar–RCA interfacial properties and nano-calcium carbonate modification, does not significantly impair chloride transport resistance and therefore does not substantially reduce concrete service life, while achieving a significant reduction in cumulative life-cycle carbon emissions.