RILEM Conference on Innovative Construction Materials and Processes for Sustainable Buildings and Infrastructure – RILEM 2026 Spring Convention

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Preface

We are delighted to chair the RILEM Conference on Innovative Construction Materials and Processes for Sustainable Buildings and Infrastructure, organized within the framework of the RILEM 2026 Spring Convention in the beautiful city of Ghent, Belgium. As testified by the numerous contributions included in this book of abstracts, the conference explores groundbreaking research, presenting scientific progress in timely and important topics related to the latest advancements in sustainable construction materials and building practices. The extended list of authors, a combination of young researchers and renowned world experts in the field, warrants thought-provoking discussions and networking opportunities with scientists and professionals from around the globe.

About two decades after the 2007 RILEM Week in Ghent, we are very happy to welcome the RILEM community again in Ghent, now for the 2026 Convention. The week-long event includes meetings of RILEM standing committees and technical committees (TCs), as well as an extended programme of award presentations, keynote lectures, TC-reports in plenary sessions, combined with numerous research presentations organized in thematic parallel sessions. Poster presentations offer a nice opportunity for further scientific interactions during coffee breaks and lunches. Our sponsor's booths invite you to interact with relevant industrial players in our field.

As a special element, we are proud to combine the organisation of the RILEM Convention and Conference with the centennial anniversary of the Magnel Laboratory of Ghent University, established in 1926, reorganized and renamed in 2020 to become the Magnel-Vandepitte Laboratory. We organize the RILEM Convention and Conference in honour of the late professor Gustave Magnel (1889-1955), world pioneer in reinforced and prestressed concrete, and the late professor Daniël Vandepitte (1922-2016), renowned expert in structural analysis and bridge design.

We are confident that the RILEM Spring Convention 2026, organized by the Magnel-Vandepitte Laboratory at Ghent University, offers a unique opportunity to share knowledge, exchange ideas, and contribute to the future of sustainable infrastructure. While studying sustainable infrastructure, we also selected to organize this important event in a sustainable way, respecting our environment, climate and resources as well as all the participants and the local community.

We thank all participants, contributors, partners, sponsors, staff and co-workers for making this event a memorable and impactful experience.

Prof. Nele De Belie & Prof. Geert De Schutter, Magnel-Vandepitte Laboratory, Ghent University

Chair of the 2026 RILEM Spring Convention & RILEM Conference on Innovative Construction Materials and Processes for Sustainable Buildings and Infrastructure

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KEYNOTE SPEAKERS

THE GLOBE CONSENSUS: PATHWAYS TOWARDS A SUSTAINABLE BUILT ENVIRONMENT

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Abstract

The Global Consensus on Sustainability in the Built Environment (GLOBE) is a joint initiative of the Liaison Committee of RILEM, fib, IABSE, ECCS, IASS, and CIB. It was established to highlight the critical role of the built environment in achieving sustainable development, and to provide a scientific basis for more effective collaboration across this domain. It seeks to translate research knowledge into coherent guidance for design practice, standardization, and policymaking.

This presentation will outline ongoing activities within the GLOBE framework, with emphasis on their relevance to RILEM's mission and its expertise in materials research. This includes the Global Building Data Initiative (GBDI) which focusses on creating a standardized protocol and platform for reporting and sharing building embodied carbon information. Strategies for linking material-level innovation with structure- and system-level design will be examined, drawing on current research, examples, and counter-examples to illustrate how these concepts can be applied in practice, supporting a more consistent and coordinated approach to sustainability in line with the aims of GLOBE and RILEM.

Keywords: Sustainable design; embodied carbon; construction materials; built environment

Built cultural heritage and earthquakes: More than 1000 shaking table tests, the new European code and applications

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Abstract. Earthquakes pose a significant threat to masonry heritage structures, whose high mass, material brittleness, and often inadequate connections make them highly vulnerable to out-of-plane collapse. While European standards guide the design and assessment of modern masonry buildings, specific provisions for historic masonry are only now being considered, creating a gap between research knowledge and regulatory practice. The STAND4HERITAGE project was initiated to address this challenge, aiming to bridge experimental research, numerical modelling, and regulatory frameworks to improve the seismic assessment and conservation of built cultural heritage. The project is structured around four interconnected work packages, which include the study of the seismic action, an extensive shaking table experimental campaign, the development and calibration of numerical models, and the definition of new standards and intervention guidelines. This paper presents an overview of the experimental campaign's outcomes, which involved over 1000 shaking table tests investigating three key out-of-plane failure mechanisms: plain single rocking block, one-way vertical bending wall, and two-way vertical bending complex U-shape structures. Dry-joint masonry specimens of varying geometries, boundary conditions, and scales are tested under both simplified inputs and recorded earthquake motions. The results provide reliable data for the calibration and validation of analytical and numerical models, produce fragility curves and performance benchmarks, and establish a robust experimental foundation to assist the future European standards.

Keywords: Masonry, Experimental campaign, Shaking table, Out-of-plane, STAND4HERITAGE, European code

See full paper in the proceedings.

ADDRESSING WORKABILITY CHALLENGES WITH CALCINED CLAYS.

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Abstract

Metakaolin, or calcined high-purity kaolinite clay, has been used in concrete mixtures for decades. Like silica fume, the cement or clinker replacement is limited to 5-15% by mass because of the negative impact of the fine, high-surface area particles on workability. As we explore and implement impure calcined kaolinite clays as supplementary cementitious materials (SCMs) and in limestone calcined clay cement (LC^3), the water demand of calcined clays becomes a stumbling block. Interestingly, other natural pozzolans that are being explored as replacement SCMs for fly ash and slag, such as pumice, perlite, or zeolites, also have high water demand. It is important to find targeted ways to address concrete workability as these new SCMs and blended cements are implemented. Two processes will be discussed in this webinar: 1) tailoring SCM composition by blending to optimize workability, and 2) combining chemical admixtures to manage workability retention.

Keywords: calcined clay; metakaolin; workability; rheology; water reducing admixtures; slump retention.

Nature-inspired innovations: Bio-based materials for resilient buildings and structures

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Abstract. The urgency of achieving carbon neutrality in the built environment demands a radical departure from conventional cementitious materials toward nature-inspired solutions that offer both low embodied carbon and enhanced functionality. This paper presents a synthesis of pioneering research streams from the bio-materials for infrastructure group at Liverpool John Moores University (LJMU), moving from laboratory innovation to regional implementation: (1) the valorisation of local agro-urban wastes into high-performance, Bio-Stabilised Earth Construction (BSEC) materials and zero-cement concretes; and (2) the development of engineered bio-composites with self-healing capabilities to ensure infrastructure durability. We demonstrate the practical application of this research through the "Bio-based Hub Liverpool" model, a collaborative initiative designed to map local waste streams, optimise supply chains, and create policy for realising net-zero construction. The paper concludes by outlining the critical role of the RILEM Technical Committee on Bio-stabilised Earth-based Construction (TC BEC) in developing performance-based standardisation and integrating biogenic carbon into infrastructure policy.

See full paper in the proceedings.

ENGINEERING SUSTAINABLE AND DURABLE PAVING MATERIALS THROUGH CHEMOMECHANICAL OPTIMIZATION

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Abstract

The design of paving materials is evolving from traditional empirical approaches toward methods grounded in material mechanisms and supported by data. As the road industry increasingly adopts bio-based, recycled, and modified binders, understanding the underlying chemical and mechanical processes becomes essential for achieving durability and sustainability. Predicting performance under real conditions requires moving beyond trial-and-error testing to approaches that link material composition, chemical ageing, and mechanical response through measurable parameters.

This keynote presents how chemomechanical optimization, combined with data-driven modelling, can accelerate this transition. By integrating techniques such as Fourier Transform Infrared Spectroscopy (FTIR), rheology, and mechanics with statistical and machine learning tools, it becomes possible to connect molecular changes to macroscopic performance and uncover the mechanisms that control ageing, compatibility, and recyclability

This approach allows large experimental datasets to be interpreted in a more meaningful way, improving the reliability of predictions and guiding the formulation of materials with extended service life. Through examples involving bio-based binders, rejuvenated mixtures, and in-situ spectroscopic monitoring, the presentation will demonstrate how combining mechanistic understanding with data-driven modelling leads to more robust material design and more circular, climate-resilient pavements.

Keywords: Chemomechanics, paving materials, durability, bio-based binders, data-driven modelling

A HOLISTIC APPROACH TO MATERIAL CONCEPT AND STRUCTURAL DESIGN WITH ADVANCED CEMENT BASED MATERIALS: A PATHWAY TO THE DECARBONISATION OF THE BUILT ENVIRONMENT

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Abstract

The continuously evolving needs of the end user in the construction industry, together with the increasing awareness about the great influence of the sector on the worldwide sustainability, require some tools to be employed by the stakeholders to drive the market towards conscious and appropriate choices. An example in this regard are advanced cement-based materials that, either by partially replacing cement with supplementary cementitious materials and virgin aggregates with recycled ones or by increasing durability also thanks to “incorporated” self-healing functionalities, are generating interest in the market thanks to their potentially better environmental performance.

A holistic approach is presented which combines materials with higher and longer lasting performance with enhanced structural functionality even under structural service scenarios encompassing extreme environmental and mechanical actions. The signature of high resilience material concept is embedded into a conceptual structural design approach where concretes are no longer regarded as providers of passive protection only, whose degradation over time has to be delayed as much as possible, but become active players in shaping their own performance as a function of the requirement in the operating scenario while retaining functionality. The design approach, suitably "nestled" into a life cycle thinking framework, which extends from cradle to gate to grave to cradle and incorporates also advanced fabrication techniques including digital fabrication and additive manufacturing, represents a key driver for advanced materials innovation uptake in concrete construction industry.

The overall performance assessment hence does no longer rely on the merely misleading concepts of material unit volume cost and environmental impact at its time of generation but is appropriately framed into a structural functional unit context all along its service life. The optimized design, together with the reduced frequency of the maintenance activities, results into consistent reductions of environmental impacts in comparison to “business as usual” solutions.

Keywords: (Ultra) High Performance Concrete, Durability, Self-healing, Life Cycle Analysis, Sustainability, Digital Fabrication.



INNOVATION:
nanotechnology
responsive polymers
active control

MAGNETO-RHEOLOGY CONTROL IN 3D CONCRETE PRINTING

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Abstract

3D printing of concrete needs to meet the contradicting requirements regarding pumpability, extrudability, and buildability. On the one hand, the material needs to flow easily to be pumped towards the printing unit and to be extruded through the nozzle. On the other hand, after the printed material reaches its final position in the printed layers, the yield stress of the mixture should be high enough to maintain its shape under its own weight and the load from upper layers. Applying interventions at the print head to rapidly increase the buildability does not affect the pumpability of the concrete mix before extrusion. Magneto-rheology control, by means of pre-added responsive additives and applying a magnetic field signal, is a promising method of active rheology control of 3D printable cementitious materials. This presentation describes the theoretical foundations of magneto-rheology control in 3D concrete printing, and a conceptual examination is presented by rheological experiments. It is found that cementitious paste with magnetic particles shows higher structural build-up after removing the pulsed magnetic field which is applied before the time sweep test. This is correlated to the possible residual magnetic clusters formed under magnetic field because of the presence of the remanent magnetization characteristic of the magnetic particles. The magneto-rheological behaviour of cement mortar using steel fibres as responsive elements is further analysed and the residual fibre aggregation in suspensions is examined. Additionally, the proof-of-concept results demonstrating how magneto-rheology can control the printability and mechanical properties of 3D printed steel fibre reinforced concrete will be presented. These findings clear the path to actively improve the buildability and print quality of cementitious materials for 3D printing by introducing a magnetic field during the extrusion process.

Keywords: Active rheology control; magnetic field; 3D concrete printing; Steel fibre.

THE ROLE OF IRON OXIDE COMPOSITION IN MAGNETORESPONSIVE CEMENT PASTES: A COMPARATIVE INVESTIGATION

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Abstract

Active Rheology Control (ARC) is a promising strategy for adjusting the rheological properties of cementitious materials on demand, which is particularly valuable for concrete 3D printing, where conflicting material property requirements must be met across the different stages of the process. This approach relies on magnetoresponsive particles, that must not only provide a sufficiently strong rheological response but also be available in quantities suitable for practical, large-scale application. In this context, residual materials have recently gained attention as a sustainable source of magnetoresponsive particles. These materials often contain varying amounts of different iron oxides that differ regarding their magnetic properties. Therefore, considering only the iron content is insufficient for estimating their suitability for ARC. Understanding how the individual iron oxide composition influences magnetorheological behavior is essential to gaining more fundamental knowledge and enabling the profound selection of suitable materials with a heterogeneous composition. This study provides a systematic, direct comparison of the magnetorheological performance of cement pastes incorporating two different inorganic construction additives, each characterized by very high contents of pure iron oxides, specifically Fe_3O_4 and α-Fe_2O_3, used as magnetoresponsive particles. The additive particles, which had comparable particle size distributions, were added to the cement pastes. A series of rheological investigations, including small amplitude oscillatory shear tests, were conducted by means of a modular compact rheometer equipped with a magnetocell. The results reveal distinct differences in the rheological behavior under applied magnetic fields, which is strongly influenced by the magnetic characteristics of the predominant iron oxide in the inorganic additive. These findings contribute to the understanding of how oxide composition affects magnetorheological behavior and provide a foundation for evaluating the suitability of compositionally variable residual materials. They also facilitate the development of effective ARC material systems in cement-based matrices, driving progress in ARC technology.

Keywords: Iron Oxides, Active Rheology Control, Cement Paste, Magnetic Stimulation, Magnetoresponsive Particles, Magnetorheological Behavior

Advanced Polymer-Cement Synergy Through In-Situ Monomer Polymerization and Calcium Acetate Coordination

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Abstract. In-situ Polymerized Modified Cementitious Composites (iPMCC), where monomers polymerize within the cement matrix leading to a more pronounced increase in flexural strength, have recently garnered significant attention from researchers. By introducing calcium acetate into the iPMCC system, the polymerization reaction and cement hydration process are promoted, resulting in the formation of a highly entangled polymer network that strengthens the interfacial bonding between hydration products and the polymer. The results demonstrate that calcium acetate-modified iPMCC exhibits enhanced flexural strength and bend toughness, without a significant reduction in compressive strength. This study provides a viable strategy for developing high-performance polymer-modified cement-based materials and underscores the critical role of the synergistic effect between in-situ monomer polymerization and calcium ions in fabricating advanced cement composites.

Keywords: Monomer in-situ polymerization, Calcium acetate, Cementitious materials, Toughness enhancement, Polymer-modified cement.

See Full Paper in the Proceedings

Functionalization Of Self-Sensing 3D Printed Mortars for Building Monitoring

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Abstract. Self-sensing materials are a promising alternative for building sensorization and Structural Health Monitoring (SHM). Cement-based materials (CBM) can acquire self-sensing capacity due to piezoresistivity (PZR) by including carbon-based components. PZR can be used to measure stress/strain by monitoring the variation of electrical resistivity. Several studies have been conducted on self-sensing cementitious materials (SSCM) with carbon-based components. However, very few address SSCM for 3D printing applications.
This investigation assessed piezoresistivity (PZR) of 3D printed CBM for self-sensing applications in Architecture, by incorporating different amounts of carbon microfibers and nanotubes. Mixtures' printability was preliminary evaluated by using an automated mortar extruder. Fractional Change Resistivity (FCR) was calculated on different specimens under cyclic load tests.
The experimental results showed the functionalization of 3D printable mortars with self-sensing capacity through the incorporation of different types of carbon-based components that fulfils the fresh and hardened properties for Architectural applications. This innovative material can be implemented in constructive elements for building monitoring.

Keywords: Structural Health Monitoring; Self-sensing Mortars; 3D Printing; Piezoresistivity; Printability.

See Full Paper in the Proceedings

VANE TESTS OF MORTAR WITH ADDED MAGNETO-RESPONSIVE PARTICLES UNDER UNIFORM MAGNETIC FLUX DENSITIES BEYOND 0.55 TESLAS

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Abstract

Active rheology control (ARC) of cementitious materials is an advancing area within concrete research, particularly in the context of 3D printing. The incorporation of magneto-responsive particles into cementitious materials allows for the adjustment of rheological behavior on-demand through external magnetic fields. When magnetized, the fresh material stiffens, as reflected by increases in apparent viscosity and storage modulus. This controllable stiffening effect is beneficial for onsite operations, including pumping or during 3D printing by enhancing layer stability. Currently, most investigations have been conducted using magneto-rheological devices (MRDs) combined with shear rheometers at the cement paste scale. Few studies have attempted to scale these experiments up to the mortar level, necessitating the magnetization of larger volumes. The field strengths achieved in these up-scaled setups typically fall short of those in MRDs, posing the risk of failing to realize the technology's full potential due to a limited rheological response. This contribution introduces a novel setup utilizing magnet technologies adapted from low-field nuclear magnetic resonance imaging and magnetic refrigeration. It enables continuous adjustability of the magnetic flux density from zero to values above 0.55 teslas while maintaining a virtually uniform field distribution throughout the sample, preventing particle migration along field gradients. A vane test is applied on the mortar scale under various magnetic fields for a cementitious system, varying the quantities of magneto-responsive particles added. Both rotating and oscillating tests are conducted. Results are compared across different flux densities and are evaluated in terms of practical challenges of field generation and magnetic interaction between the magnet assembly and the sample. Therewith, novel insights into practical applications, e.g., 3D printing processes, are gained.

Keywords: Active Rheology Control, Cement Paste, Magnetic Stimulation, Magneto-responsive Particles, Magnetorheological Behavior, Mortar

Assessment of sodium silicate delivery via embedded vascular networks in cracked concrete exposed to aggressive environments

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Abstract. This study investigates the performance of a self-healing system using a vascular network (VN) fabricated with 3D-printed polylactic acid (PLA) embedded in concrete, designed to deliver a sodium silicate (SS) healing agent. Laboratory-scale tests were conducted using two aggressive exposure conditions: (1) marine environment, simulated using synthetic seawater (ASTM D1141-98, 2021) for six months; and (2) chloride environment using 33 g/L NaCl solution for three months. Realistic cracks of 100 µm and 300 µm width, were induced in concrete specimens at 28 days, which were subsequently exposed without preconditioning. Crack closure during exposure was analyzed by optical microscopy, while chloride ingress was evaluated through silver nitrate spraying on fractured surfaces. In the marine environment, the SS healing agent effectively mitigated chloride ingress, reducing penetration by 59% for 100 µm cracks and 56% for 300 µm cracks after three months of exposure compared to the reference samples. However, prolonged exposure led to expansive reactions, with ettringite and calcium carbonate detected. As the PLA of the VN is unlikely to account for the expansion, the network most likely enhanced seawater ingress, increasing interaction with hydration products, though partial VN degradation cannot be excluded. Under chloride-only conditions, the crack width influenced the healing response, and no expansion was noted after 3 months of exposure. In 100 µm-wide cracks, SS reduced chloride ingress by 56%, while for 300 µm-wide cracks, the healing agent reduced ingress by 50%. These findings suggest that the SS delivered through the VN remains effective in promoting self-healing under both marine and chloride environments. However, long-term stability and unintended effects of the VN on the ingress of aggressive media warrant further investigation to optimize performance and avoid side effects such as expansion.

Keywords: Self-healing concrete, Vascular network, Sodium silicate, Chloride ingress, Marine environment.

See Full Paper in the Proceedings

Development of Bio-Encapsulated Phase Change Materials via Combined Coacervation and Spray Drying for Building Integration

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Abstract. The continuous rise of the global population has driven a sharp increase in energy consumption, highlighting the urgent need for more efficient and sustainable solutions in the building sector. Phase Change Materials (PCMs) are promising candidates for thermal energy storage (TES) because they absorb and release heat during phase trans. However, these materials face limitations related to leakage, thermal conductivity, and stability within alkaline building environments. This study investigates the microencapsulation of two commercial bio-based PCMs, CrodaTherm 24W and PureTemp 25, via complex coacervation combined with spray drying, using carboxymethylcellulose (CMC) and potato proteins (PP) as shell materials, followed by a calcium carbonate coating. Encapsulation efficiencies were 89.4 ± 1.01 % for CrodaTherm 24W and 87.9 ± 1.84 % for PureTemp 25. Although CrodaTherm-based Microencapsulated Phase Change Material (MPCM) showed a slightly higher EE%, the highest melting enthalpy was observed for the PureTemp-based sample (63.27 J/g). CrodaTherm-based MPCM also exhibited anomalous thermal behavior, including multi-peaked crystallization upon cooling and lower-than-expected latent heat, which suggests core–shell interactions or incomplete crystallization that warrant further investigation. In contrast, PureTemp-based MPCM displayed well-defined, reproducible phase transitions and stable thermal reversibility, making it a promising candidate for TES applications in building materials.

Keywords: PCM, Microencapsulation, Thermal Energy Storage, Coacervation, Spray dry, Carbon-neutral buildings.

See full Paper in the Proceedings

Active Rheology Control of 3D Printable Cement-Based Materials with Embedded Thermally Responsive Polymers

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Abstract. Complex and sometimes conflicting rheological requirements at different stages of the extrusion-based 3D concrete printing process, pose significant challenges for traditional rheology pre-control during mixing. Consequently, immediate active rheology control has attracted increasing attention in extrusion-based 3D concrete printing. In this study, we propose a novel approach to actively control the rheological properties of 3D printable cement-based materials (3DPCM) using thermally responsive polymers. Poly(N-isopropylacrylamide) polymer (PNIPAM) synthesized via free radical polymerization was incorporated to produce thermally responsive 3DPCM. To evaluate the response in structural build-up behavior of samples with PNIPAM under a varying temperature field, the small-amplitude oscillation shear test was conducted following temperature protocols that varied within the range of 15 °C to 65 °C. The effects of PNIPAM dosage and water-to-binder ratio (W/B) were studied. Results indicate that PNIPAM reduces the initial storage modulus of samples, while enhancing the thermally responsive structural build-up behavior. The storage modulus significantly increases once the temperature reaches a critical value. This phenomenon can be further enhanced as the PNIPAM dosage increases. The W/B has a limited effect on the critical response temperature, but it affects the response intensity a lot. With the reduction in W/B, the improvement in storage modulus becomes more remarkable due to the increased concentration of PNIPAM.

Keywords: Additive manufacturing, Cement, Thermal stimulation, Polymer, Rheology control.

See Full Paper in the Proceedings.

EFFECT OF CONCENTRATION OF HARD MAGNETIC PARTICLES ON RHEOLOGICAL PROPERTIES OF RESPONSIVE CEMENTITIOUS MATERIALS

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Abstract. To further facilitate the application of active rheology control such as for 3D printing, responsive cementitious materials which can sustain the magnetorheological response after the magnetic invention needs to be developed. This research investigates the effect of concentration of hard magnetic particles on sustained rheological properties of responsive cementitious materials after a short magnetic intervention (5 s). Neodymium iron boron particles were added into the cement pastes with the replacement rate of 5%, 10%, 15% and 20% by volume of cement powder. The storage modulus of responsive pastes after intervention was determined by strain-sweep tests. A new type of responsive mixtures which can sustain the magnetoresponse was verified. The experimental results show that the sustained rheology response can be increased and improved significantly by increasing the added amount of hard magnetic particles.

Keywords: Hard magnetic particles; NdFeB; Responsive cementitious materials; Remanent magnetization.

See Full Paper in the Proceedings.



MATERIALS:
cementitious
non-cementitious
natural building materials

BOND BEHAVIOR AND MECHANICAL PERFORMANCE OF UHPC REINFORCED WITH DATE PALM FIBERS

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Abstract

Ultra-High-Performance Concrete (UHPC) is characterized by its exceptional strength, durability, and ductility, achieved through optimized particle packing, low water-to-binder ratio, and steel fibers reinforcement. However, the high economic and environmental costs associated with steel fibers motivate the development of more sustainable reinforcement alternatives. This study evaluates the feasibility of incorporating Date Palm Fibers (DPF), an abundant agricultural byproduct, as a natural reinforcement in UHPC. Steel fibers were partially replaced with DPF at levels up to 100% by volume. The fibers were collected, chemically treated, and cut to standardized lengths to simulate the aspect ratio of steel fibers. The dry DPF exhibited an average water absorption capacity of 186%, which significantly influenced both the effective water/binder ratio and the workability of fresh UHPC. Increasing DPF content resulted in reduced flowability due to internal water uptake, highlighting the importance of accounting for fibers-induced water demand in UHPC mix design.

Mechanical performance was assessed through compressive and flexural strength testing, alongside detailed evaluation of fibers-matrix bond behaviour. Results showed a progressive decrease in strength with higher DPF replacement levels, attributable to the lower stiffness and tensile capacity of natural fibers compared to steel. Nevertheless, mixtures containing 40–60% DPF demonstrated an optimal balance between mechanical performance and enhanced ductility, exhibiting improved post-peak deformation capacity and energy absorption. SEM analysis confirmed strong fibers-matrix interlock, minimal interfacial gaps, and effective crack-bridging by DPF, in contrast to the interfacial debonding frequently observed with steel fibers.

Overall, the study validates the potential of DPF as a sustainable reinforcement for UHPC, particularly in applications where ductility, weight reduction, and environmental benefits are prioritized over maximum strength performance.

Keywords: UHPC, Date palm fibers, Natural fibers, Ductility, SEM, Sustainable construction

Tailored Poisson's Ratio-reinforced Cementitious Composites for Flexural Applications

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Abstract. The use of Additive Manufacturing (AM) to create reinforcements for cementitious composites has become a popular research topic in recent years. One illustrative example is the integration of 3D-printed auxetic reinforcements into cementitious matrices, which exhibit superior energy absorption due to their negative Poisson's ratio. This presents the opportunity to tailor the Poisson's ratio of reinforcements to align with local stress distributions and enhance structural efficiency. In this study, Tailored Poisson's Ratio-reinforcements (TPR) were proposed, characterized by a linear gradient of Poisson's ratios along the height of the reinforcement to accommodate varying stress profiles within beams. Specifically, the top chords of TPR exhibit negative Poisson's ratios (auxetic), undergoing lateral contraction under compression and providing confinement to the surrounded matrix. Conversely, the bottom chords possess positive Poisson's ratios, contributing to lateral contraction under tension. These lateral deformations cause a shift in the principal stress state of the confined matrix, extending the loading path in stress space and actively delaying failure. Three novel Tailored Poisson's Ratio-reinforced Cementitious Composite (TPRCC) designs are developed and tested under four-point bending in this study. Experimental recordings indicate increases in load capacity and toughness of up to 191% and 6900% with respect to plain mortar, respectively.

Keywords: Poisson's ratio, Auxetic, Cementitious composites, Polymeric reinforcement, 3D printing, Flexural properties.

See Full Paper in the Proceedings

DIGITAL IMAGING AND MICRO-CT FOR THE RHEOLOGICAL CHARACTERIZATION OF HYDRAULIC BINDER SYSTEMS

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Abstract

This research introduces an innovative micromechanical framework for estimating the plastic viscosity of fluid suspensions composed of hydraulic binders. The methodology integrates X-ray microtomography with automated image analysis to determine key microstructural parameters—namely, the maximum packing fraction and intrinsic viscosity—of suspensions formulated with Portland cement and natural hydraulic lime. Dry powder samples were analysed to extract detailed information on particle size distribution and morphology. These morphological parameters were then employed to calibrate the Krieger–Dougherty model. Suspensions with different water-to-binder ratios were prepared, and the dosage of superplasticizer was optimized using zeta potential measurements to ensure effective dispersion. The plastic viscosity was inferred from the descending branches of the flow curves measured at varying shear rates. A mathematical expression was developed to relate the intrinsic viscosity to particle circularity, providing a quantitative link between morphology and rheological behaviour. The findings validate the use of image-based characterization techniques for accurately capturing particle shape, a critical factor in the rheological modelling of non-Newtonian suspensions. The proposed methodology enables a reliable prediction of plastic viscosity, thereby enhancing the fidelity of micromechanical models when compared with experimental data. This approach offers a robust tool for the optimization of binder formulations in sustainable construction materials.

Keywords: Rheological characterization; X-ray microtomography (micro-CT); Automated morphological analysis; Micromechanical modelling; Hydraulic binder systems.

MICROSCOPIC MOISTURE ABSORPTION PROCESS AND PROGRESSIVE DAMAGE ANALYSIS OF CONCRETE BASED ON TWO-PHASE FLUID SOLID COUPLING AND PHASE FIELD METHOD

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Abstract

Approximately 80% of cracks in concrete structures during service are induced by the coupled effects of temperature and moisture. Unlike damage from short-term extreme loads, this degradation, governed by time-varying material properties, is uncertain, irreversible, and nonlinearly cumulative. Traditional research often focuses on extreme environments, leaving the damage mechanism under non-extreme hygro-thermal cycles insufficiently explored. This study bridges this gap by investigating the capillary water absorption process to systematically reveal the micro-damage evolution and durability degradation of concrete. A multi-scale numerical framework is developed: at the macro-scale (10mm), moisture diffusion is simulated via a simplified Fick's second law; at the micro-scale (100μm down to 50nm), a two-phase fluid-solid coupling model, employing the Navier-Stokes and Cahn-Hilliard equations, is utilized to simulate capillary uptake and the consequent mechanical response of pore walls. Simulations highlight the critical role of pore structure. The moisture diffusion rate in the Interfacial Transition Zone surpasses that in the cement paste, explaining the characteristic slow-then-fast absorption. At finer scales, pore geometry drastically influences absorption kinetics and stress concentration. At the nanoscale, these localized stresses can reach hundreds of megapascals, far exceeding the applied capillary pressure, thereby identifying them as a key mechanism driving progressive damage in cement-based materials during hygro-thermal cycling.

Keywords: Concrete, Progressive thermal and moisture damage, Capillary water absorption, Two-phase fluid solid coupling, Fracture phase field method, Multi-scale

Enhancing Early Age Strength in High-Filler, Low-Water Systems with C-S-H Seeding

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Abstract. To reduce the environmental impact of cement production and save energy, high-filler low-water (HFLW) systems are a promising solution. These systems depend on low water-to-binder ratios and the use of supplementary cementitious materials (SCMs) to significantly reduce the clinker factor. As for other systems with SCMs reacting less rapidly than ordinary Portland cement (OPC), strength development at an early age may be a challenge for HFLW systems when further implemented in concrete applications. This study evaluated mortar mixes with an HFLW binder composed of ordinary Portland cement (OPC), limestone filler, and ground granulated blast furnace slag (GGBS), with varying water-to-binder ratios (W/B). Selected mixes were further optimized by adding calcium-silicate-hydrate (C-S-H) seeding at 2%, 3%, and 5% by binder weight. The results show that C-S-H seeding improved the early age compressive strength, with a 95% strength increase after 1 day and a 45% increase after 3 days compared to the samples without C-S-H seeding. Different methods for the application of C-S-H seeding were also investigated, and it was observed that mixing the C-S-H with the mixing water and using a high shear mixer was the most efficient way to introduce the C-S-H to the mix. The approach was upscaled to the concrete scale, and the mix with 3% C-S-H seeding demonstrated the same strength improvement of 95% after 1 day, achieving a strength of 43 MPa after 7 days, along with the required fresh properties and air content. This research strengthened the interest of C-S-H seeding addition to improve HFLW binders' early age strength, enhancing the ability to design binders with high clinker reduction without losing critical properties.

Keywords: limestone filler, GGBS, ternary binder, calcium-silicate-hydrate seeding, compressive strength, CO_2 reduction.

See Full paper in the Proceedings

DESIGN AND CHARACTERIZATION OF REPAIR MORTAR USING OYSTER AGGREGATES AND ALKALI-ACTIVATED SLAG BINDER

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Abstract

Structures around the coast, such as seawalls and harbours, face environmental challenges that speed up their deterioration. One common method of maintaining these structures is the use of repair mortars applied to restore the eroded joints and surfaces. This work presents a case study on the formulation and characterization of an environmentally friendly repair mortar designed for the repair of protective dams and structures located at the Socoa fort on the French Basque coast. These structures are built from rocks and concrete blocks bonded with mortar. However, the mortar is subjected to harsh stresses, such as expanding and contracting rocks, salt weathering, and constant wave impacts, which lead to cracking and debonding over time. Currently, the site is repaired multiple times per year with an industrial mortar primarily consisting of an Ordinary Portland Cement (OPC) binder and plastic fibres, among others. This poses both environmental and economic challenges considering the size of the site and the volume of mortar used for repairs annually. The mortar proposed by the current study is made from oyster sand, alkali-activated slag (AAS) binders, and calcite filler. A formulation strategy tailored to the peculiarities of seashell aggregates was adopted to optimize the mechanical performance of the oyster mortars. Different formulations of the oyster mortar with varying water-to-cement ratios were created, and their mechanical and fresh state performance was compared with the industrial mortar. The performance of the newly formulated mortar was assessed in accordance with applicable standards for repair mortars to verify its viability before field applications. In terms of compressive and elastic performance, the oyster mortar met the minimum standards for use in concrete repairs. Finally, a site application was executed, with field inspections ongoing.

Keywords: Eco-friendly repair mortar, Alkali-activated slag binders, Oyster shell aggregate, Coastal structure restoration, Durability

Engineering sustainable binders: the role of calcined marl and clays in LC3- systems

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Abstract. In response to the urgent need to reduce carbon emissions and mitigate the environmental footprint of cement production, low-clinker systems, particularly ternary blends such as Limestone Calcined Clay Cement (LC3), have emerged as promising sustainable alternatives. This study explores the potential of locally sourced raw materials from the western region of Chania, Crete, Greece, to contribute to the development of LC3-type binders.

Three clay samples were thermally activated at 700 °C and subsequently reacted with saturated lime solutions to evaluate their pozzolanic activity. In parallel, a local marl was calcined at 800 °C and hydrated to assess its potential as a reactive filler and binder component in hydraulic mortar formulations. The reactivity of the calcined materials was investigated through their ability to form calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) phases, key contributors to strength development and durability in cementitious systems.

Uniaxial compression tests were conducted on hardened cubic samples over a curing period of up to three months to evaluate the evolution of their mechanical performance. Surface roughness analyses were performed on fracture surfaces following three-point bending tests, using microscopic examination techniques to assess surface topography and microstructural features. Results revealed that metakaolin-rich clays displayed significantly higher pozzolanic reactivity with lime, compared to clays with lower kaolinite and higher calcite content. Mechanical testing showed a progressive increase in strength over time, highlighting the importance of extended curing. The performance of these alternative binders proved promising, with strength values comparable to the cement-based control reference.

Keywords: calcined marl; calcined clay; pozzolanic activity; hydration; cement substitution

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Evaluating Drying Techniques for Alkali-Activated Materials: Nitrogen adsorption and Thermal Insights

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Abstract. The microstructure of cementitious materials is highly sensitive to drying, as the fine pores generate substantial capillary stress during moisture loss. Various drying methods, including oven drying (OD), freeze drying (FD), solvent exchange, and supercritical drying have been extensively studied and their effects on the Portland cement systems have been reported. While these techniques are well-established for traditional cement systems, research on alkali-activated materials (AAMs) remains limited. In this study, a comprehensive evaluation of several drying methods – including oven drying at 105 °C, 80 °C, and 60 °C; freeze drying; solvent exchange using isopropanol, ethanol, and methanol; and vacuum drying was conducted on high-calcium alkali-activated materials. The effects of different drying methods on surface area and thermal decomposition were assessed using the Brunauer-Emmett-Teller (BET) surface area using N_2 gas adsorption and thermogravimetric analysis (TGA) at both early and later curing ages. The finding shows that the BET surface area of the high Ca AA-pastes prepared using the solvent exchange was much higher compared to the direct drying method, indicating better preservation of the microstructure. While the mass loss obtained from TGA showed that the all the drying method did not stop the reaction immediately after the drying methods were applied for 1- day aged sample, the solvent exchange seems to stop the hydration closer to the 1- day than those from oven drying. 28-day aged samples were not significantly affected by the drying method used in this study.

Keywords: Alkali activated, modified solvent exchange, BET surface area, freeze drying, stoppage hydration.

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BALANCING POROSITY AND STRENGTH IN CONCRETE INCORPORATING OYSTER SHELLS: A STRATEGY FOR HIGH-MASS SHELL REUSE

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Abstract

Large quantities of oyster shell waste are generated locally, and recycling them into concrete offers environmental benefits. In recent years, our team has developed innovative concrete by replacing the entire granular structure with various crushed seashell waste (e.g., oyster, scallop, nacre). The specific preparation and crushing of the seashell waste, along with optimizing both the granular skeleton assembly and the concrete formulation, yield a composition suitable for creating pathways, artificial beaches, and stairwells in an industrial context. However, crushed oyster shells tend to produce high intergranular porosity (>60%) due to their flaky or needle-like shapes, which compromises mechanical strength, while conventional aggregates lead to lower porosity (between 30% and 40%). This study aims to maximize oyster shell usage while maintaining acceptable porosity and strength for further applications.

With four aggregate types (classical sand, classical coarse, oyster sand, oyster coarse), each at various dosage levels, the experimental combinations are extensive. A staged approach was implemented, starting from the earlier optimization of the entire oyster granular skeleton (oyster sand and oyster coarse). Classical sand and classical coarse were introduced to reduce the skeleton's intergranular porosity while keeping the total mass of oyster waste above 50%.

First, a mix design is proposed with 50% classical sand and an optimized combination of sand and coarse oyster shell. Then, another mix design is proposed with 50% classical coarse aggregate and a different optimized mix of sand and coarse oyster shell. All mixes were cast and tested after 28 days of controlled curing underwater. Mechanical properties are compared in terms of compressive strength, tensile strength and stiffness properties to identify the best compromise between seashell waste valorization and mechanical performance for a subsequent size effect investigation on the influence of seashell aggregate on fracture process zone evolution and failure properties.

Keywords: Oyster waste valorization; Granular skeleton design; Intergranular porosity; Mechanical performance; Sustainable concrete.

A review on activated clays as key precursors in the formulation of sustainable hybrid alkali-activated cements.

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Abstract. An urgent global challenge for the construction industry is the reduction of greenhouse gases emissions. Therefore, the industry must transition towards the adoption of more sustainable construction practices, including the use of eco-efficient materials, to achieve net-zero emissions targets. One strategy for reducing the environmental impact of construction is using less Portland cement (PC) in concrete. This can be achieved by adopting new hybrid alkali-activated cements (HACs) produced with low PC clinker contents (30-50 wt.%) blended with supplementary cementitious materials (SCMs) such as fly ash or blast furnace slag and activators. In recent years, the interest in using calcined clays have increased significantly, as these materials are potentially available in many regions worldwide and can help meet the growing demand for sustainable construction materials. However, commercially available sources remain limited, and large-scale applications are still emerging. Hence, studies evaluating the potential for producing HACs using different clay resources are very limited. This paper analysed the potential of mixed clays as SCMs, focusing on enhancing their pozzolanic reactivity through thermal (TA) and/or mechanochemical (MCA) activation processes, and presents a brief overview of the main techniques used to assess structural and mineralogical transformation in activated clays. The review also highlights and discusses the application of optimised activated clays in HACs systems incorporating PC, varying clay contents (50 – 70%), when using as alkali activator sodium sulphate (Na_2SO_4).

Keywords: Eco-efficiency, Clay minerals, Thermal activation, Mechanochemical activation, Hybrid alkali-activated cements.

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ENHANCING COMPRESSIVE DUCTILITY OF CEMENTITIOUS COMPOSITES THROUGH AUXETIC REINFORCEMENT

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Abstract

Herein we propose a highly compressible auxetic cementitious composite (ACC). Unlike conventional cementitious materials, including plain concrete and fibre reinforced concrete, the newly developed composite shows strain hardening upon uniaxial compression, with the stress continuously increasing up to almost 40% strain. In addition, at the early compression stage (up to around 10%), the composite exhibit highly recoverable deformation, up to 20 times higher than the base cementitious matrix. In addition, the ACC shows fatigue damage until the stiffness/strength and energy dissipation plateau values are reached after 500 cycles. At 2.5 % strain amplitude, the plateau stiffness/strength is approximately 120 MPa/3 MPa, while these values are only 25 MPa/1.2 MPa at 5 % strain amplitude. In contrast, the energy dissipation plateau of the ACC is independent from the amplitude and remains at 0.05 J/cm^3. Due to the strain hardening behaviour, the ACC exhibits significantly improved energy dissipation capacity compared to both the cementitious matrix and the auxetic reinforcement component. This is achieved by tailoring the composite action, i.e., using a 3D printed thermoplastic polyurethane (TPU) auxetic structure as reinforcement. A rotating square auxetic mechanism was designed to achieve the desired cracking behaviour: the horizontal ACC cells enable large deformability by enlarging the crack width under confinement of the reinforcement, while the vertical cells work as a stiffening phase to ensure load resistance. The outstanding mechanical performance of the ACC shows great potential for applications in engineering practice when high compressive ductility is required, for example yielding elements for squeezing tunnel linings.

Keywords: 3D printing; Auxetic structures; Energy Absorption; Cementitious Composites

Use of Waste Glass as Supplementary Material in Cementitious Systems

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Abstract. The incorporation of waste glass into concrete significantly decreases cement consumption, thereby reducing CO_2 emissions, and fostering a circular economy. Due to its high amorphous silica content, glass exhibits pozzolanic properties that enhance the long-term strength, durability, and resistance to chemical attack of concrete. However, depending on its production, glass can contain high alkali levels, which may increase the risk of alkali-silica reaction in concrete. Utilizing waste glass with fineness less than 45μm can mitigate this issue, as the material becomes more reactive and exhibits enhanced pozzolanic characteristics.

In this study, waste glass from a window glass manufacturer in Greece, was evaluated as a potential pozzolanic material. Following an analysis of the raw material's properties, including chemical composition, density, and mineralogical characteristics, the waste glass was ground to a fineness of under 45 μm and employed as a supplementary binder for cement paste production. Various proportions of waste glass (0%, 10%, 20%, 30%, and 50%) were combined with Portland cement to create composites, which were prepared with standard consistency. The influence of the addition of the waste glass on properties such as heat of hydration and setting time of the pastes were measured immediately after mixing. Shrinkage was monitored over a period of 40 days. Additionally, the pozzolanic behavior of the waste glass – cement pastes was analyzed using XRD and TG at various ages. The flexural and compressive strength of the samples were tested at 7, 28, and 90 days, showing an initial decrease of the strength at 7 days, up to 60%. However, overtime, the mixtures containing glass showed a higher increase in strength compared to the reference mix (higher than 50%). The performance evaluation of the waste glass confirmed its pozzolanic properties, indicating its potential as a supplementary cementitious material.

Keywords: waste glass, supplementary cementitious materials, sustainability.

See Full Paper in the Proceedings

PERFORMANCE EVALUATION OF UHPC INCORPORATING WASTE OLED POWDER AS A PARTIAL CEMENT SUBSTITUTE

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Abstract

This study investigates the potential of utilizing waste OLED display powder as a partial cement substitute in ultra-high-performance concrete (UHPC) to enhance material sustainability without compromising mechanical and chemical *performance.* Organic Light-Emitting Diode (OLED) displays generate light through electroluminescent organic thin films and are fabricated on multilayer glass substrates composed mainly of high-purity silica (SiO_2 , 62.1%), alumina (Al_2O_3 , 21.2%), and alkaline-earth oxides, producing the inorganic glass-based waste powder used in this study. Owing to its high-silica and low-calcium composition, which is comparable to that of Class N fly ash, the OLED powder exhibits limited but potential pozzolanic reactivity. As OLED displays are increasingly replacing LCDs in global electronic devices, the volume of OLED-derived glass waste is expected to rise worldwide. Four mix proportions were prepared by replacing 0%, 25%, 50%, and 75% of ordinary Portland cement (OPC) with OLED powder. The physical and chemical properties of the materials were analyzed through FT-IR spectroscopy, TG/DTG analysis, and NMR to evaluate hydration reactions and the formation of C–S–H and $CaCO_3$. The results indicate that the specimen with 25% OLED replacement exhibited enhanced hydration reactivity, as evidenced by intensified Si–O–Si vibrational peaks and increased $Ca(OH)_2$ content. This contributed to the formation of refined C–S–H gel and improved microstructure. Mechanical performance was evaluated through compressive, tensile, and static pull-out tests. The 25% replacement specimen demonstrated the highest compressive strength (184.76 MPa), a 10.9% increase in tensile strength, and improved strain capacity and energy absorption. These enhancements are attributed to the micro-filler effect of OLED powder, which improved matrix density and fiber-matrix interfacial bonding. However, excessive replacement (≥50%) led to reduced calcium availability and lower reactivity, resulting in diminished hydration products and weakened mechanical performance.

Keywords: Ultra-high-performance fiber-reinforced concrete, OLED glass powder, Fiber pullout resistance, Tensile performance

CLAY ROOF TILES MANUFACTURE. INTER-RELATIONSHIP BETWEEN RAW MATERIALS SELECTION, PRE-TREATMENT & PROCESSING PARAMETERS WITH MICROSTRUCTURE & GELIVITY

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Abstract

Ceramic roof tiles and frost action often represent a significant issue in humid and cold climates. Fired clay-based materials that absorb water are particularly vulnerable to superficial exfoliation and loss of mechanical strength when temperatures fall below 0°C. This phenomenon, influenced by the raw materials' physical and mechanical characteristics (e.g., porosity), the industrial manufacturing process, and the design and construction of the roofing system, can compromise the service life of the finished product. In some cases, materials that are guaranteed to last up to 30 years shown signs of delamination after only four years of exposure to the elements.
This research investigates various batches of ceramic roof tiles produced by an Italian company, some of which have been returned by costumers due to premature deterioration despite the laboratory tests confirming their durability. The aim of the project is to understand the reasons behind this inconsistency. The initial phase of the research involves the study of the mineralogical composition of the fired materials through XRPD analysis, as well as examining their porosity distribution using MIP and BET methods. Further analyses will explore the microstructure and the internal stresses of the tiles though the use of the X-Ray Microtomography and 3D Image Analysis. Simultaneously, the study will assess the extent of frost damage, its development on roofing structures, and the potential factors influencing it (such as building location) using image processing and mapping techniques applied to three case studies, from which damaged tiles were collected by the company.

Keywords: Gelivity, porosity, frost resistance

Engineered Porosity via Polystyrene Beads in Gypsum Plasters: Experimental Validation and Microstructural Control

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Abstract. Like many sectors across the European Union, the gypsum industry is actively seeking strategies to reduce its environmental footprint by lowering product density while maintaining quality and performance standards. To address this, a resource-efficient strategy that reduces gypsum and water consumption, and thereby lowering energy use without sacrificing mechanical performance is pursued. In this study we establish the relationship between the three-dimensional characteristics of air voids such as volume fraction, size distribution, sphericity, polydispersity, packing density, and tortuosity within the gypsum matrix and the resulting mechanical performance of the material. Standard and advanced characterization techniques, such as mercury intrusion porosimetry (MIP), X-ray micro-computed tomography (μCT), and mechanical testing were used to investigate the gypsum core structure and its mechanical properties. These characterizations served as a benchmark for quantifying the relationship between pore structure and material properties in gypsum plaster. Additionally, a straightforward methodology was developed to produce model porous samples with controlled porosity parameters using polystyrene (PS) beads. These polystyrene beads of known diameter were added in the gypsum plaster paste and mechanical tests were carried out. The samples were compared with identical counterparts from which polystyrene had been leached out. The results indicate that polystyrene can effectively serve as a surrogate for air voids in representing porosity within the gypsum matrix.

Keywords: Gypsum, porosity, X-ray micro-computed tomography (μCT), multiscale microstructure characterization, sustainability, mechanical properties

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LITHIUM MINING WASTE IN CONCRETE PRODUCTION

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Abstract

The UK, with its growing number of lithium mining industries in Cornwall and North England, and aspiration to become self-sufficient in battery production, is an ideal market for accelerating the commercial adoption of lithium mining waste in the cement and concrete industry, contributing to a more sustainable and low-carbon construction sector. This study summarise the preliminary findings of the EPSRC-funded LITHICRETE project (2025-2028).

Lithium mining waste, a by-product of the lithium extraction process for battery production, holds promise in reducing the carbon footprint of concrete when used as Portland cement replacement. Lithium slag (LS) primarily consists of amorphous glassy phases and crystalline compounds, including calcium (aluminium) silicates. It exhibits pozzolanic properties, similar to those of other supplementary cementitious materials (SCMs), e.g., conventional fly ash (FA), GGBS, and silica fume, making it a suitable candidate for Portland Cement (PC) replacement. In this study, we replaced PC with up to 20% wt. of lithium slags, generated during extraction and processing of lithium ore. We investigated the mechanical and physical properties at 28 and 90 days of curing, and compared to those of conventional fly ash concrete. Preliminary results confirmed that 20% of LS can be used to replace PC to produce structural grade concrete, with minimal strength loss (less than 10%) when compared to that of fly ash concrete. Isothermal calorimetry showed that the cumulative heat of hydration is comparable to that of PC and FA, showing similar hydration kinetics. Electrical resistivity measurements indicated that LS concrete has moderate-to-low chloride penetration potential, whilst its porosity is similar to that of FA concrete.

Keywords: supplementary cementitious materials, lithium slag, bulk electrical resistivity

Hydration Kinetics, Fresh and Hardened State Properties of Seawater Mixed Cementitious Materials Blended with Red Mud

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Abstract. The disposal of red mud—a byproduct characterized by chemical hazards and low-level radioactivity—poses significant environmental and economic challenges. Consequently, its sustainable reutilization has become a crucial focus in materials research. In recent years, an increasing number of studies have examined the incorporation of red mud as a mineral admixture in cementitious systems. Due to its high chloride-binding capacity, red mud is considered a promising additive for concrete mixed with seawater. In this study, the hydration kinetics, time-dependent fresh-state properties, and mechanical strength of mortars incorporating red mud at four dosages (0%, 10%, 20%, and 30%) with seawater were systematically investigated. The findings revealed that the high superplasticizer demand associated with the high specific surface area of red mud, combined with the reduced water consumption because of its lower hydration reactivity, resulted in only limited changes in the fresh-state properties of the composite mixtures over time. In contrast, the compressive strength of the composite mixtures remained higher than that of the control mixture prepared with freshwater, primarily due to the filler effect of the fine red mud particles and the enhancing influence of seawater. These results suggest that red mud can be a suitable sustainable mineral additive for reinforced seawater concrete, increasing chloride binding capacity without compromising mechanical performance compared to freshwater one.

Keywords: Seawater, Red mud, Hydration, Superplasticizer, Sustainability.

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An experimental study on partial replacement of Portland cement with zeolite powder in pervious concrete

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Abstract. Given the pressing challenges of climate change, the civil engineering industry must adopt more sustainable practices. One approach is the use of supplementary cementitious materials (SCMs), as cement production is a major contributor to CO_2 emissions. Zeolite, a naturally occurring microporous aluminosilicate formed through volcanic activity, exhibits pozzolanic proper-ties and has been explored as an SCM. This study investigates the effects of zeolite as a partial cement replacement in pervious concrete (PC), replacing Type 1L cement at 0%, 25%, and 50% by weight. We evaluated its influence on mechanical and hydraulic properties through compressive strength, void content, infiltration rate, and microscopy analysis. Specimens were cast in Summer 2024 and tested after eight months. Results show that increasing zeolite content significantly reduced both mechanical and hydraulic performance. Control specimens exhibited 25.5% void content and an infiltration rate of 8.8 mm/s. At 25% and 50% zeolite replacement, void content dropped to 23.1% and 22%, with infiltration rates decreasing to 6.1 mm/s and 2.5 mm/s, respectively. Compressive strength declined by 46% and 66% at 25% and 50% replacement levels. These losses are likely due to zeolite's lower pore size distribution and reduced early reactivity, which limit the formation of calcium silicate hydrate (C-S-H) and calcium hydroxide ($Ca(OH)_2$), essential for continued pozzolanic reaction and strength gain. Microscopy revealed a hissing behavior in zeolite mixes upon wetting, likely caused by internal energy retained during dehydration. Upon contact with water, this energy is released as pressure, producing an audible hiss. This phenomenon may relate to zeolite's potential for energy retention and resistance to freeze-thaw cycles reported in the literature. Future work will optimize zeolite dosage across cement types and assess its potential for pollutant removal, energy retention, and freezethaw durability to enhance the sustainability and performance of pervious concrete.

Keywords: Zeolite, Supplementary Cementitious Material, Pervious Concrete, Portland Cement, Freeze-Thaw Resistance.

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UTILISATION OF EXCAVATED LONDON CLAY FROM TUNNELING OPERATIONS IN CONCRETE – UPDATES FROM A CROSS-INDUSTRY MULTIDISCIPLINARY INNOVATION INITIATIVE

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Abstract

As part of a major tunnelling project in the United Kingdom, significant volumes of clay are being excavated in the wider London area. The excavated material would normally be treated as waste, sent to landfill or incorporated into landscaping. Instead, a method is developed to turn the excavated clay spoil into a construction resource with a particular focus on supplementary cementitious material. This study reports the latest developments within the REAL and Ex-Clay industrial innovation projects aiming to transform London Clay spoil into such construction resources. It encompasses overviews of investigations on the plastic, micro-structural and chemical properties of raw and calcined London Clays, as well as hardened concrete and mortar properties produced with those clays. Developments thus far have demonstrated that London Clay, in its calcined form, can be a suitable supplementary cementitious material for low/medium strength concrete. Concrete mixes with compressive strengths of up to 30-50 MPa, and Portland cement replacement levels of up to 70% have been developed utilising calcined waste London Clay and limestone in binary and ternary formulations. Insights on environmental considerations, London Clay processing methods and concrete production intricacies with calcined London Clay are also provided.

Keywords: Calcined clay, London Clay, waste utilisation, concrete, circular economy

DESIGN OF CHEMICAL ADMIXTURE FORMULATION FOR SUSTAINABLE SELF-COMPACTING CONCRETE BASED ON CEM II/B-M (Q-LL)

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Abstract

This study aims to investigate and better understand the interaction between chemical admixtures and CEM II/B-M (Q-LL) to support the development of tailored admixture formulation for sustainable self-compacting concrete (SCC). A wide range of polycarboxylate ethers (PCE), representing six different PCE technologies (VPEG, HPEG, MPEG, EPEG, other) were evaluated to assess their specific interaction with CEM II/B-M (Q-LL) in comparison with CEM I and a low-clinker cement CEM III/A.

Mortar formulations followed SCC design principles. Admixture performances were assessed by critical dosage via flow measurements at five dosages, workability retention was followed for 60 minutes, torque-resistance test using a ToniMIX Visco-Expert mixer, hydration through isothermal calorimetry on paste and 24-hour compressive strength testing.

Results showed that CEM II/B-M (Q-LL) required ~ 50% higher admixture dosage to achieve comparable fluidity to CEM I and CEM III/A. No saturation dosage could be clearly identified. Nevertheless, the effect of the admixtures on retention exhibits an opposite trend compared to conventional systems. Whereas the workability of CEM I and CEM III/A decreased gradually over time, CEM II/B-M (Q-LL) remained stable or even increased slightly. The admixtures, despite PCE technologies, can be classified in slow, medium and fast adsorbing, which ranges from ready-mix to precast concrete application. As expected, the slower the adsorption the lower the initial workability and the higher the torque-resistance. Interestingly, after 45 minutes EPEG technologies show the best workability retention, with the lowest torque-resistance, suggesting that EPEG helps maintaining low yield stress. Hydration studies confirmed that admixtures extended the dormant period by 2-6 hours leading to a 20-25% reduction in 24-hour compressive strength compared to the reference without admixtures.

The higher dosage requirements, altered retention behaviour, delayed hydration, and reduced early strength highlight the need not only for different admixture chemistries but also for tailored formulation approaches specific to this cement.

Keywords: Limestone calcined clay cement, Chemical admixtures, Self compacting concrete, Fresh properties

DURABILITY ASSESSMENT OF COASTAL NUCLEAR POWER PLANT CONCRETE: FLY ASH REPLACEMENT AND SEAWATER IMMERSION

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Abstract

This study analyzed the diffusion characteristics of concrete structures at nuclear power plants that are directly exposed to seawater due to their coastal location. The binder's coagulation characteristics, compressive strength over time, and diffusion coefficient were evaluated through saltwater immersion tests. The mix used in this study was based on a mix table from a previous study that predicted the durability of existing nuclear power plant concrete structures[1]. It also included the essential service water(ESW) and tunnel mixes, which are concrete structures that are directly exposed to seawater. The ESW and Tunnel mixes are mixes in which 20% of the binder is replaced with fly ash(FA). A control mix with 100% ordinary portland cement(OPC) as the binder was examined and compared to the FA mixes to determine the impact of using fly ash. The initial and final setting times of the 100% OPC mix were approximately 20 minutes faster than those of the FA mixes, though similar. The compressive strength of all mixes exceeded the 91-day design standard strength of 5,000 psi(34.5 MPa). The nuclear power plant concrete mix showed a higher increase in strength after 28 days than the control mix. This is expected due to the long-term strength increase caused by the pozzolanic reaction. Through the saltwater immersion experiment, the chloride diffusion coefficient was found to be lowest in the following order: control, TUN-N, ESW-N, and ESW-H. These results are believed to be due to the nuclear power plant concrete mix containing FA, which reduces pore size through a pozzolanic reaction and makes the pore structure denser.

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Keywords: concrete, durability, fly ash, seawater immersion.

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Hydration Kinetics and Phase Assemblage Modeling Of Blended Cements

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Abstract: In pursuit of sustainable material design, novel blended cements with high levels of supplementary cementitious materials (SCMs) are being increasingly used. Although the hydration of these blended cements has been extensively studied in the literature, prediction of their hydration kinetics and phase assemblage remain poorly understood, especially in ternary and quaternary blended systems. This study proposes to determine the hydration kinetics and phase assemblages based on the isothermal calorimetry test, the theoretical framework proposed by modified Parrot-Killoh, and thermodynamic simulation. The isothermal calorimetry measurements were performed on various Portland cements blended with BFS (40% and 60%) and MK (30%) as well as a ternary blend (30% MK and 15% LS) at a water/binder ratio of 0.5. Additionally, quantitative X-ray diffraction was used to characterize the phase assemblages for the thermodynamic model. The result has shown that incorporation of BFS blends has led to the formation of hemicarbonate as the main AFm phase; however, the incorporation of MK blends has converted hemicarbonate to the formation of stralingite phase, with an increasing amount at later age.

Keywords: hydration kinetics, blended cements, isothermal calorimetry, thermodynamic modeling

See Full Paper in the Proceedings.

Mechanical characterization of macrosynthetic fibre reinforced concretes with calcined clay-blended cements

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Abstract. The construction industry is a major contributor to global CO_2 emissions, with Portland cement production alone responsible for 5–8% of the total, primarily due to its clinker-intensive process. To reduce this environmental impact, the partial replacement of clinker with supplementary cementitious materials (SCMs) has gained significant attention. Calcined clay, due to its high pozzolanic reactivity, availability, and low-carbon profile, is emerging as a key SCM in sustainable binder development.

This study reports the findings from an experimental program assessing the mechanical and time-dependent behavior of structural concretes incorporating a commercially available blended cement, formulated with 7% calcined clay. This percentage reflects a realistic industrial substitution level defined by production constraints and the technical-operational criteria of the cement manufacturer. Four fluid-consistency (class F) concretes were studied: two reference strength classes targeting $f_{ck,28}$ = 25 and 40 MPa, and two polypropylene macrofibre-reinforced concretes (3 and 6 kg/m³) designed to meet $f_{ct,fl,28}$ = 3.5 MPa. Standardized tests were performed at 7, 28, 90 and 120 days to evaluate compressive strength, tensile strength, modulus of elasticity, flexural behaviour, and drying shrinkage.

All concretes met or exceeded the specified performance targets. Indirect tensile strength at 28 days ranged from 3.1–3.9 MPa, and the elastic modulus developed within 30–39 GPa. Increasing fibre dosage notably enhanced post-cracking residual capacity, supporting crack-control-oriented design. Overall, the results support the feasibility of low calcined-clay substitution for structural concretes while quantifying the mechanical and serviceability-related contributions of polypropylene macrofibres.

Keywords: *calcined clay; blended cements; limestone-calcined clay systems*

See Full Paper in the Proceedings.

Preliminary Mechanical and Durability Characterization of Concrete with Partial Replacement of Fine Aggregate by Olive Pit Ash

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Abstract. The integration of sustainable materials into construction is increasingly important to reduce the environmental impact of cement-based composites. This study explores the mechanical and durability performance of concrete in which natural sand is partially replaced by biochar derived from olive pits, a common agricultural by-product in Mediterranean regions. Concrete mixes with 4%, 10%, and 20% volumetric replacement of fine aggregate were assessed. All mixes proved satisfactory mechanical strength, with minor variations across replacement levels. This limited variation may be attributed to the small substitution volume and the unchanged content of cement and coarse aggregates. In terms of durability, all biochar mixes exhibited lower capillary water absorption compared to conventional concrete, indicating enhanced resistance to water ingress. These results suggest -at this stage- that olive pit biochar can be used as a partial sand substitute without significantly compromising performance, while supporting circular economy strategies and contributing to carbon sequestration.

Keywords: Concrete, biochar, olive pit ash, mechanical properties, durability, sustainability.

See Full Paper in the Proceedings.

EXPLORATORY STUDY ON THE EFFECT OF ASH TYPE AND CONTENT ON CARBON-CURED CEMENT-FREE BINDERS

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Abstract

Cement production is a significant contributor to global CO_2 emissions, driving the research and development of alternative binders with a reduced environmental impact. The present study explores the potential of carbon-cured, cement-free mixtures using various industrial ashes as reactive components. Specifically, the present study investigates the compatibility of fly ash and bottom ash from different waste streams (municipal solid waste incineration, wood biomass and co-combustion) in a carbonation-based hardening system. The chemical composition of each ash differs significantly, affecting their reactivity and CO_2 binding potential. Cement-free mixtures were prepared with 20%, 30%, and 40% ash content by mass, with the remainder comprising a steel slag (Cx). All samples were mixed at a constant water-to-binder ratio of 0.10. Curing was conducted under accelerated carbonation conditions in a controlled chamber at 60°C, 60% CO_2 concentration, and 24 hours of exposure. The objective of this exploratory study is to evaluate the influence of the ash type and dosage on early-stage carbonation under uniform curing conditions. Preliminary findings indicate a notable variability in response among different ashes, suggesting a strong dependency on chemical composition. This study contributes to the understanding of how industrial by-products can be effectively valorised in carbon-cured systems. The outcomes provide valuable insights for the development of sustainable, cement-free construction materials capable of both mechanical performance and carbon sequestration, thereby advancing circular construction practices.

Keywords: Carbon-cured concrete, incineration ashes, alternative binders, mechanical properties

Effect of Tire and Industrial Steel Fiber Mix on Structural-Grade Concrete Performance

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Abstract. The disposal of waste tires poses a significant environmental issue, as non-combustible steel fibers account for approximately 15–25% of a tire. Recycling these fibers into concrete offers a sustainable alternative to commercial fibers, potentially reducing both solid waste and CO_2 emissions. However, earlier studies demonstrated that raw tire steel fibers (RF) alone cannot fully replace industrial steel fibers (IS) in cement composites. As a solution, combining RF with IS in a hybrid form is suggested to enhance performance while maximizing the use of recycled materials. This pilot study investigates the use of a fiber mix (MF) comprising 60% RF and 40% IS in high-strength concrete made with locally available materials. Standard concrete specimens were prepared and tested in accordance with ASTM standards. Compressive strength (CS), elastic modulus (EM), and water absorption (WA) were measured using 82-day-old specimens. The results showed a notable increase in the EM, 8%, and a reduction in water absorption, 20.2%, for MF-reinforced concrete. These results showed that the selected fiber mix enhances both the mechanical performance and durability of the concrete. For future studies, it is recommended to consider the influence of MF on the in-depth mechanical attributes and structural behavior of reinforced concrete members.

Keywords: Recycled Tires, Steel Fibers, Fiber Reinforced Concrete, Durability, Sustainable Construction.

See Full Paper in the Proceedings.

A MICROSTRUCTURAL INVESTIGATION TOWARDS EXPLORING SEAWATER IN CONCRETE

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Abstract

This paper presents selected findings from an ongoing experimental investigation on the effects of seawater as a constituent in concrete. The study focuses on the formation of Friedel's Salt ($C_3A{\cdot}CaCl_2{\cdot}10H_2O$), additional ettringite ($C_3A{\cdot}CaSO_4{\cdot}32H_2O$) and brucite ($Mg(OH)_2$) in concrete, resulting from the chemical reactions with the high concentration of Cl^-, SO_4^{2-} and Mg^{2+}, respectively, present in seawater. Most of the studies reported in the literature focused on 28-day compressive strength, where the results show similar compressive strength compared to reference concrete with freshwater. However, the effects of the above-identified hydration products on the long-term properties of concrete mixed with seawater have not been understood and studied with the required level of scientific rigour. The present study investigated the long-term effects of Friedel's salt, ettringite and brucite based on variable concentrations of seawater by conducting compressive strength tests, XRD analyses to identify and quantify the hydration products, and SEM-EDX analyses to determine their morphology and specify any accompanying microcracks. The results showed that the extreme concentration of Cl^- (29 g/l), SO_4^{2-} (3.8 g/l) and Mg^{2+} (2 g/l) is found to increase the strength at early age (7-day) by up to 18%, reduce the strength at 28-day and 91-day by up to 8% and 11.5%, respectively, compared to regular concrete, with prediction for further reduction over time. The continued degradation was due to the formation and development of the stated hydration products, as they have different morphology, molar volume and crystallisation mechanisms than regular hydrated cement products. This led to the formation of microcracks due to expansions as determined from the microstructural analysis. The paper also identifies a method for reducing the formation of these products by reducing the calcium hydroxide ($Ca(OH)_2$) content, thereby enabling the use of seawater without weakening the hardened and durability properties of concrete.

Keywords: Concrete; Seawater; Compressive strength; Microstructure; Durability; Cementitious hydration products

LONG-TERM WATER IMBIBITION AND STRAINS OF CEMENT PASTES WITH INCINERATION ASHES

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Abstract

Understanding the interplay between humidity-induced changes in the calcium silicate hydrate (C-S-H) structure and macroscopic transport mechanisms remains a challenge in conventional cementitious systems, and even more so when incorporating alternative materials. This study aims to bridge that gap by investigating the coupled behaviour of strains and imbibition in cement pastes containing varying levels of municipal solid waste incineration ash (MSWIA) as a partial cement replacement (0%, 20%, 30%, and 50%). A combination of analytical techniques was employed to assess hydration progress, phase development, and durability: thermogravimetric analysis (TGA), X-ray diffraction (XRD), water absorption (WA) and imbibition tests. At 28 and 91 days, TGA and XRD analyses quantified hydration products such as portlandite (CH), calcium silicate hydrate (C-S-H), and carbonates. WA and imbibition tests provided insights into open porosity, capillary pore connectivity, and water uptake behaviour. Long-term imbibition experiments were conducted on pastes at 28 and 91 days to assess the influence of MSWIA on water transport dynamics. High-precision strain gauges were employed to capture real-time external deformations during water imbibition. These synchronous measurements were enabled by a custom-built experimental setup, which allowed for a detailed analysis of the coupling between transport phenomena and mechanical response.

The study presents the results of the relative impact of cement replacement by MSWIA on imbibition and correlates these with strain development. Long-term monitoring (over 3 months) provides insights into time-dependent behaviour. Additionally, special attention is given to the relationship between primary and secondary imbibition rates. Ultimately, this research aims to enable the prediction of long-term transport behaviour (years) from short-term experimental data (months), contributing to the design of more durable and sustainable cementitious materials.

Keywords: capillary imbibition, municipal solid waste incineration ash, strains, long-term behaviour

Synergistic Effect of Steel, Carbon, and Polypropylene Fibers on UHPC Performance

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Abstract

Ultra-high-performance concrete (UHPC) is a critical material in modern infrastructure, known for its exceptional compressive strength (exceeding 150 MPa), superior durability, and unique material composition. UHPC typically consists of fine aggregates, mineral admixtures such as silica fume, and a high cement content. However, compressive strength alone does not ensure high performance or sustainability. To improve its mechanical behavior, the incorporation of fibers into the UHPC matrix is essential. This study investigates the influence of triple fiber reinforcement, micro steel fibers, carbon fibers, and polypropylene (PP) fibers on the mechanical and fresh properties of UHPC. Carbon fibers, known for their high strength-to-weight ratio, chemical inertness, excellent tensile strength, and high elastic modulus, offer a promising alternative to conventional steel fibers in enhancing the performance of UHPC.

The primary objective of this research is to analyze the synergistic effects of combining steel, carbon, and PP fibers to enhance flexural strength and overall toughness. Although the inclusion of fibers slightly reduces the compressive strength of UHPC, the results demonstrate that PP fibers effectively mitigate the risk of spalling. Moreover, the combination of fibers significantly enhances the electrical conductivity of UHPC, with carbon fibers playing a dominant role due to their higher conductivity compared to steel fibers. Microstructural analysis using scanning electron microscopy (SEM) reveals a uniform distribution of fibers throughout the UHPC matrix. Additionally, the observations confirm both pullout and fracture mechanisms in carbon and steel fibers, contributing to improved toughness and energy absorption capacity of the composite.

Keywords: Ultra-High-Performance concrete (UHPC), Triple Fiber Reinforced, Carbon Fibers, Steel Fibers, Polypropylene Fibers, Scanning Electron Microscopy (SEM)

See full Paper in the Proceedings

Investigation of Ashes from Municipal Solid Waste Incineration (MSWI) and their Application as Supplementary Cementitious Material

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Abstract. This study investigates the reactivity of four types of incineration ashes, using the R3 test to assess their potential as alternative cementitious materials. The most reactive ash was selected for further evaluation in blended cement mortar. Blended mortars containing 0%, 20%, and 40% municipal solid waste incineration fly ash (MSWI FA) were prepared at water-to-binder (l/b) ratios of 0.4, 0.5, and 0.6. Fundamental performances, including setting time, flowability, flexural strength, and compressive strength, were systematically evaluated to determine the feasibility of MSWI FA incorporation. To mitigate potential expansion issues associated with residual metallic aluminium, a sodium hydroxide (NaOH) pretreatment was applied to the ash before mixing. The findings contribute to a better understanding of ash reactivity and provide guidance for optimising the use of MSWI FA in sustainable cement-based construction materials.

Keywords: Municipal Solid Waste Incineration Ash, Supplementary Cementitious Material, R3 Method, Reactivity, Mix Design.

See Full Paper in the Proceedings.

ALKALI-ACTIVATED MATERIALS UTILISING CALCINED CLAYS AS SUSTAINABLE PRECURSOR

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Abstract

Alkali-activated materials (AAMs) containing wastes and secondary raw materials (WSRMs) allow reduced CO_2 emissions, resource consumption and waste arisings. WSRM precursors are often combined with other Al-Si-rich substances to improve reactivity and ensure adequate mechanical and chemical durability. However, high-purity alumosilicates, such as high-grade metakaolin, are in short supply and/or expensive due to demand from other industries. Therefore, this study systematically investigates several mixed clay samples, calcined at 400 to 1000°C in 100°C intervals, as possible alternatives. Mineralogical and chemical analyses reveal the initial clays to differ in particular in their sheet silicate contents (mainly kaolinite, chlorite and muscovite). During calcination, these phases are gradually transformed into their amorphous (metaclay) analogues at around 500-600, 500-800, and 700-900°C, respectively. ^{27}Al MAS-NMR and FTIR were used to confirm the transformations to be driven by dehydroxylation reactions and octahedral to tetrahedral Al coordination changes. For verification, the calcined clay powders were utilised in AAM pastes with granulated blast-furnace slag, coal fly ash and various mineral WSRMs. The resulting paste specimens exhibited adequate compressive strengths, *e.g*. up to 75 MPa for a blast-furnace-slag – clay mixture after 7 days of reaction. AAM pastes containing clay calcined at 700°C and various mineral by-products exhibited 7-day compressive strengths of up to 40 MPa, verifying the feasibility of low-grade kaolinitic clays as corrective substances for waste-based AAMs. We gratefully acknowledge the contributions of Leila Legat and Lisa Schuller regarding the characterisation and AAM mixing tasks. The study was carried out in the course of the GECCO$_2$ Christian Doppler Laboratory. The financial support by the Austrian Federal Ministry of Labour and Economy, the Christian Doppler Research Association and several industry partners is gratefully acknowledged.

Keywords: calcined clays, alkali activation, waste-based binders, AAM

MECHANOCHEMICAL ACTIVATION OF LOW-PURITY CLAYS: COMPARATIVE EVALUATION OF MILLING TECHNOLOGIES AND UPSCALING POTENTIAL

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Abstract

Clays with low kaolinite content and other associated clay minerals, often referred to as low purity or common clays, are abundant worldwide. While already used in clinker production, their application as supplementary cementitious materials (SCMs) remain largely unexplored due to their low chemical reactivity. Traditional activation methods, such as calcination, are often ineffective to induce pozzolanicity when applied to these types of clay, particularly those rich in illite, muscovite, or mixed-layer phases. Mechanochemical activation (MCA) is an electrified route that can be applied instead of calcination to enhance the reactivity of low-purity clays. By applying high-energy grinding, MCA induces mineral structural disorder, dehydroxylation, and amorphization, which are key structural changes associated with improved chemical reactivity.

In this study, a low-purity clay was treated using three different milling systems: a planetary ball mill, a vibratory disc mill, and a horizontal drum mill. Key process parameters, including grinding time, rotational speed, and ball-to-powder ratio, were optimised for each system. Particle size analysis and X-ray diffraction confirmed reduced particle size, progressive structural breakdown, and increased amorphization with increasing milling intensity. These effects were more pronounced when using the planetary ball mill. Chemical reactivity, assessed via isothermal calorimetry (R^3 test), showed that MCA-treated clays can achieve cumulative heat release values exceeding 500 J/g of SCM. Upscaling trials using a horizontal drum mill indicated potential transferability of laboratory scale conditions, although a higher energy input is required to achieve comparable results. These findings demonstrate the potential of MCA as a promising and scalable technology for converting abundant, low-purity clays into suitable SCMs.

Keywords: Mechanochemical activation, grinding efficiency, planetary ball mill, disc mill, horizontal mill, pozzolanic activity

INFLUENCE OF SUPERPLASTICISER TYPE AND DOSAGE ON THE FRESH AND HARDENED PROPERTIES OF ENGINEERED CEMENTITIOUS COMPOSITES WITH LIMESTONE CALCINED CLAY CEMENT (ECC-LC3)

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Abstract. The transition towards low-carbon construction materials necessitates the redesign of high-performance cementitious systems traditionally reliant on high volumes of Portland cement. Engineered Cementitious Composites (ECC), while offering excellent ductility and crack control, contribute significantly to CO_2 emissions due to their high cementitious content. Limestone Calcined Clay Cement (LC3), a ternary binder composed of Portland cement, calcined clay, and limestone, presents a promising alternative for reducing the environmental impact of ECC. To explore this potential, this study investigates the influence of superplasticiser type and dosage on the fresh and hardened properties of LC3-based ECC mixtures, aiming to optimize rheological behaviour and strength development for sustainable, high-performance composites. ECC mixes were prepared with a 55% replacement of Portland cement by LC3, including Portland cement, calcined clay, and limestone. Calcined clay with a reactivity value of 410 J/g of SCM, as per ASTM C1897, was used to produce the LC3. Four commercial superplasticisers were used at dosages of 0.5%, 0.75%, 1.0%, and 1.2% by weight of binder. Fresh properties, including slump, deformation factor, flow time, and rheology, as well as the compressive strength of these mixtures, were tested to determine the compatibility of superplasticiser to obtained desired fresh and hardened properties in the ECC mixes. Superplasticiser type and dosage critically influence rheology and mechanical performance, with higher dosages enhancing workability, deformation, and flow time, leading to improved particle dispersion and compressive strength, highlighting the importance of admixture optimization in LC3-based ECC for sustainable, high-performance applications.

Keywords: Engineered cementitious composites (ECC); Limestone calcined clay cements (LC3).

See full Paper in the Proceedings

EFFECT OF AUTOGENOUS HEALING ON WATER PERMEABILITY OF CRACKED MICROFIBRE-ENHANCED 3D TEXTILE REINFORCED CEMENTITIOUS COMPOSITES (3D TRCs)

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Abstract

Textile Reinforced Cementitious (TRC) composites offer a promising alternative for traditional steel-reinforced concrete, enabling the development of more slender, lightweight structural elements for both new construction and retrofitting applications. 3D TRCs, incorporating three-dimensional textiles, offer superior performance compared to 2D TRCs, particularly with regard to manufacturing simplicity and flexural properties. As cement-based materials, however, 3D TRCs remain prone to cracking, which can compromise durability by allowing the ingress of potentially harmful substances. Integrating short polypropylene (PP) microfibres into the material's cementitious matrix can result in controlled crack formation, promoting the development of more and narrower cracks. Due to their reduced width, these cracks are more likely to physically seal through autogenous healing, the inherent characteristic of cementitious materials to close their own cracks over time, thereby reducing permeability and enhancing durability. The presented study investigates the effect of autogenous healing on the low-pressure water permeability of cracked 3D TRCs with 1.0 v% of integrated PP microfibres. The cracked material was subjected to a 28-day healing period during which it was exposed to one of three conditions: complete water immersion, wet-dry cycling, or standard laboratory conditions. Crack sealing was studied by means of microscopy and Ultrasonic Pulse Velocity (UPV) measurements. The water permeability was assessed through low-pressure water permeability tests on uncracked, cracked and potentially healed specimens. The findings show substantial visual crack closure at the surface, especially in specimens fully submerged in water. Both the cracked specimens exposed to wet-dry cycles and those submerged in water, however, tended to demonstrate increasing UPV values, accompanied with a significant recovery of water tightness as a result of autogenous crack sealing, both reaching flow rate values of the uncracked material. This indicates that microfibre-enhanced 3D TRCs can recover durability properties through autogenous healing, even when water is not continuously available.

Keywords: Textile Reinforced Cementitious composites (TRCs); 3D Textiles; Polypropylene (PP) microfibres; Autogenous healing; Water permeability; Ultrasonic Pulse Velocity (UPV)

Use of Iron Mining Waste Rock as Cement Replacement in Concrete

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Abstract. Concrete production has a significant environmental impact, mainly due to the high CO_2 emissions associated with Portland cement manufacturing and the extraction of raw materials, such as limestone and clay. In parallel, iron ore mining generates large quantities of waste rock, an inert by-product removed during the extraction process, which is typically stockpiled in piles, pits, or dams, requiring extensive disposal areas and long-term environmental management. The reuse of this abundant material in cementitious materials presents a promising strategy to reduce both environmental burden and cement consumption. This study investigates the incorporation of iron mining waste rock as a partial cement replacement in concrete, focusing on the effects of substitution on physical and mechanical properties. Concrete mixtures were produced with 20% and 30% of the cement replaced by waste rock, and consistency, fresh density, compressive strength, Young's modulus, water absorption, voids content, and hardened density were evaluated. In support of the mixture design, the waste rock was briefly characterized and its cement performance index determined through standardized compressive strength comparisons, which indicated that the material does not act as a reactive addition and that its contribution is primarily physical. Concrete mixtures with waste rock showed slight reductions in consistency, density, and compressive strength compared to the reference mixture; however, these losses were not critical and remained within acceptable ranges for general applications. Other physical and mechanical properties also exhibited minor reductions with increasing replacement levels. The results demonstrate the technical feasibility of using iron mining waste rock as an inert filler in concrete, enabling partial cement replacement without significant loss of performance, and support more sustainable construction practices by promoting the reuse of mining by-products, in line with circular economy principles.

Keywords: Iron mining waste rock, Cement replacement, Concrete, Mechanical properties, Physical performance.

See full paper in the proceedings.

SELF-HEALING OF EARLY- AND LATE-AGE CRACKS IN CONCRETE WITH CRYSTALLINE ADMIXTURES: UPV AND IMAGE ANALYSIS ASSESSMENT

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Abstract

Concrete is one of the most widely used construction materials due to its high compressive strength and versatility. Its low tensile strength, however, makes it susceptible to cracking. Even though microcracks are not always structurally critical, they can significantly compromise durability by allowing the ingress of aggressive agents. Enhancing the material's intrinsic self-healing ability is a strategy for mitigating this issue, and crystalline admixtures have been explored for this purpose. Although self-healing concrete has been widely studied, few investigations address its effectiveness in repairing late-age cracks. This study evaluated the self-healing capacity of concrete with and without crystalline admixture, pre-cracked using the Brazilian split test at two different ages: 3 days (average crack width ≈ 180 µm) and 42 months (average crack width ≈ 235 µm). Internal healing was assessed by ultrasonic pulse velocity (UPV) testing, and surface crack closure was evaluated through image analysis using an optical microscope and ImageJ. After cracking, all specimens were kept submerged for the duration of the experiment, and measurements were taken at 7, 14, 21, 28, and 56 days. Results showed that, for early-age cracks, both concretes exhibited a minor increase in UPV over time, with the control mix achieving greater recovery than the mix containing crystalline admixture, although the overall improvement was limited (below 8%). For samples cracked at 42 months, UPV also showed no meaningful improvement, suggesting limited internal self-healing under the tested conditions regardless of cracking age. In contrast to the limited UPV recovery, surface-closure analysis indicated significant healing, with the concrete containing crystalline admixture showing a recovery of 77% for cracks created at 3 days and 89% for cracks created at 42 months, while the control mix exhibited a recovery of 70% for 3-day cracks and 95% for cracks created at 42 months.

Keywords: Self-heling concrete, Crystalline admixture, Ultrasonic pulse velocity, Image analysis, early-age cracking, late-age cracking.

Petrographic features associated with alkali-aggregate-reactions in tropical aggregates

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Abstract

The lack of petrographic indicators to associate aggregates with AAR and other insitu concrete deffects has lead to random quarying of concrete aggregtes. This has resalted in several structural failures, and extra monitoring and repair cost within developing sub-Saharan Africa. Depending on the degree of alteration of rock, some mineral phases dissociate in alkaline cement pore solution, reacting with the alkali to form products that absorb moisture, expan and innitiate microcracks. These reactions are referred to as alkali-aggregate reactions (AAR). As a preliminary endevour to prevent deliterious AAR and ensure rezilience of structures built using tropical aggregates, 10 granitic and 4 basaltic operational quaries within Cameroon where sampled. The sampled aggregates were petrochemically and petrographically characterised, then graded and leached in two alkaline/lime solutions, based on KOH and NaOH, at 40±2°C for 26 weeks. Periodic analysis of leachates' extracts, using ICP-OES, reviews release of alkali, silicon and iron by basaltic aggregates and sulfur by some of the granitic aggregates. Reduction in hydroxide ion concentration was most significant in the basaltic species, associating to their quite elevated contents of releasable iron and silicon. Newly formed phases were identified by XRD and FTIR of leached residues against as-collected powdered samples. The deliterious AAR-indicator minerals of the basaltic aggregates were identified as cristoballite and micro-crystalline quartz, associated to potetial alkali-silica reaction (ASR). Quartz crystals of the granitic species were more or less stable in the alkali media. However, abondance mica and releasable sulfure is a call for concern. In-situ concrete degradation with these aggregates can be associated to ASR, in reactive basalts; and internal surfate attack (ISA) in granitic species. Fe release and precipitation is a potential propagator of AAR and ISA via de-alkalisation of cement pore solution.

Keywords: petrography, alakali-aggregate reactions, internal sulfate attack, tropical aggregate, granite, basalt.

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Validation of the empirical factors from the dewar packing model for particle interference of fine and coarse aggregate mixtures

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Abstract. Dewar's particle packing model incorporates the interaction diagram of Powers and offers significant advantages for industrial application due to its manageability which is related to the limited number of required input parameters compared to other particle packing models. Moreover, Dewar demonstrated that applying the interaction diagram in concrete mix design is an effective method for optimizing material use in concrete. The basic concept is that when two materials are mixed, the voids ratio of the combined aggregate mixtures is calculated taking into account particle interference. The change in voids ratio with varying fine fraction is graphically represented in an interaction diagram, consisting of six key points, of which four change points. These change points are determined by empirical factors, amongst others. Experimental voids ratio diagrams of combined monosized sieved aggregate fractions are used to determine the applied empirical factors to validate/update the Dewar's particle packing theory. From the experimental interaction diagrams, it is assumed that the wall effect is greater than the model predictions for the materials used in this study. It was found that by adapting the empirical factor k_{int}, used to calculate the notional width factor Z, a better agreement between experimental results and the model can be obtained, which should be further verified in future research.

Keywords: Particle packing modelling, Interaction diagrams, Aggregate mixes.

See full paper in the proceedings.

SUSTAINABLE ALKALI-ACTIVATED MATERIALS WITH BIOCHAR ADDITION

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Abstract

In this study, novel sustainable alkali-activated pastes incorporating various types of waste and modified with small amounts of biochar were investigated. Specifically, both powdered construction and demolition waste, as well as brick waste, were evaluated as partial replacements for the primary precursor, metakaolin. Additionally, small amounts of biochar, up to 5 wt% of the total precursor content, were added to the mixes to investigate its impact on the behaviour of the composite materials.

The workability in the fresh state, along with the physical, mechanical and durability properties in the hardened state of the different pastes, were studied and compared to a reference mix without biochar.

The results show that the addition of small amounts of biochar can increase the development of the mechanical properties and the durability of the alkali-activated composite materials. This enhancement is attributed to biochar's capacity to regulate moisture content and optimise the microstructure of the material.

Keywords: Biochar, alkali-activated materials, construction and demolition waste, brick waste, mechanical properties, durability

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Long-Term Performance Evaluation of Concrete Exposure Blocks Incorporating Sulphide-Bearing Aggregates: A Study on more than 13 Years of Exposure

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Abstract

Concrete incorporating deleterious amounts of sulphide-bearing aggregates (SBA), notably pyrrhotite and framboidal pyrite, has been found to generate internal sulphate attack resulting in significant deterioration within a few years in the field. This concrete pathology has affected approximately 2000 housing foundations in the Trois-Rivières region (TR), Quebec, Canada. Outdoor exposure sites were established in TR and in Montreal (Canada), between 2010 to 2012, in order to better understand the mechanisms of deterioration of concrete elements incorporating SBA. The TR site holds metric-size concrete blocks that were extracted from housing foundations (in TR and from Connecticut, USA) just prior to their demolition. The Montreal exposure site contains similar size blocks cast with known concrete mixture designs and different reactive (MSK) and non-reactive aggregates. The concrete blocks on both sites were monitored for cracking and expansion development since their establishment.

At the TR exposure site, a good correlation was observed between cracking and expansion development in local foundation walls showing different degrees of initial damage. Similar trends were observed for the Connecticut blocks; however, the absolute expansion and cracking values differed.

At the HQ exposure site, significant expansion and cracking were observed after 13 years of monitoring in blocks made with MSK. The concrete mixture design, notably the cement content and the w/c, do not seem to impact significantly on the overall reaction/expansion to date. However, the cement type (i.e. Low-heat LH, which has low-alkali and C_3A contents) seems to lower the rate and ultimate expansion observed. Furthermore, the use of a better-quality concrete mixture design (i.e. 375 kg/m^3 of cement, w/c of 0.5) did not prevent deleterious expansion and cracking in the exposure blocks.

Keywords: Pyrrhotite, sulphide-bearing aggregates (SBA), exposure blocks, outdoor exposure sites, oxidation reaction, internal sulphate attack (ISA).

See full paper in the proceedings.

THERMAL AND MECHANICAL PERFORMANCE OF CAC CONCRETE EXPOSED TO MOLTEN SALT AND HIGH-TEMPERATURE CYCLES

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Abstract

With the growing implementation of solar energy technologies, the development of efficient and cost-effective thermal energy storage systems has become increasingly important. Molten salt latent heat storage (MS) is a technology that stores thermal energy by changing the state of salts from solid to liquid at a constant temperature. These MS are confined in two steel tanks (cool and heat) or in a single tank using the thermocline system. To reduce the high cost of MS in the thermocline tank, filler materials can partially replace salt. However, conventional Portland cement concretes exhibit severe degradation: loss of strength, cracking, and chemical decomposition when exposed to temperatures above 500 °C, limiting their long-term stability. In contrast, calcium aluminate cement (CAC)-based concretes, although they also undergo degradation, form less unstable phases after dehydration, therefore offer improved durability under these conditions. This study focuses on concrete produced with calcium aluminate cement and a calcium aluminate-based synthetic aggregate with controlled granulometry and high thermal stability. The objective is to investigate the effect of high temperature on the thermo-mechanical and microstructural properties of CAC-based concrete subjected to thermal cycling. The analysis focuses on compressive strength, thermal conductivity, and ultrasonic pulse velocity after the first and tenth heating cycles, aiming to quantify progressive degradation. Tests were conducted within a temperature range of 200 °C (melting point of the commercial MS used) and 500 °C (onset of salt decomposition). Results reveal that the most significant changes occur during the initial thermal exposure, where compressive strength decreases by approximately 50% and thermal conductivity by around 30%, while subsequent cycles induce smaller additional variations. Despite this degradation, the CAC-based concrete demonstrated good residual performance, highlighting the critical importance of material compatibility for long-term thermocline tank operation.

Keywords: Calcium Aluminate Cement (CAC), Thermal aggregate, concrete, molten salt, thermal cycling, heat storage

ISOLATING THE INFLUENCE OF QUENCHING-INDUCED AND GRINDING-INDUCED DEFECTS ON TRICALCIUM SILICATE HYDRATION

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Abstract

To help further lower the clinker factor of blended cements and improve their early age strength, there is a renewed focus on understanding, and improving, the reactivity of clinker. Alite is the main clinker phase responsible for strength development of Portland based cements. Previous studies have generally shown that a higher defect density in alite enhances its hydration; however, it is not yet well understood what are the specific contributions of different types of defects, i.e. substitutional, quenching-induced, and grinding-induced. In this study, we used combinations of annealing and grinding steps to isolate the effects of quenching- and grinding-induced defects in tricalcium silicate (C_3S). T1 C_3S was synthesized from reagents using the 'kilo scale' synthesis method. Quenching-induced defects affected the height of the main hydration calorimetry peak more than its timing; whereas grinding-induced defects strongly affected both the height and timing of the main hydration peak. The effect of annealing was dependent on the defect state of the C_3S: the increase in length of induction period after annealing was longer for samples which had been ground more intensively. Whilst previous studies have showed some evidence of 'defect relaxation' in intensively ground C_3S, no change in induction period was observed up to 28 days. These findings open up the potential for more precise 'defect engineering' of clinker phases to improve their reactivity in blended cements.

Keywords: alite, cement, grinding, hydration, defects

Extrudable LC^3 foamed composites reinforced with recycled carbon fibres for automated production

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Abstract. The construction sector is under intense pressure to become more sustainable due to the significant CO_2 emissions coming from cement production. A key strategy is the extensive use of alternative binders in substitution of pure cement clinker. In this regard, Limestone Calcined Clay Cement (LC^3) shows great promise due to its easy adaptability on current technology. This study focuses on lightweight cementitious materials based on LC^3, integrating foam and recycled carbon fibres (rCF) from end-of-life Fibre-Reinforced Polymers (FRP). The aim is to enhance the mechanical properties and foam stability as well to promote circularity. The resulting Fibre-Reinforced Foamed LC^3 ($FRFLC^3$) mix was developed to achieve a lower material density that is suitable for lightweight applications in civil engineering. The primary objective was to compare the fundamental properties (workability, density, flexural strength, and compressive strength) of foamed mix without rCF, which was considered the benchmark, and the $FRFLC^3$ mix in their fresh and hardened states. The results confirmed that the addition of rCF successfully enhanced the mechanical properties of the composite and improved its workability for extrusion. Furthermore, preliminary extrusion trials demonstrated that the $FRFLC^3$ mix had a satisfactory strength-to-density ratio and exhibited excellent print quality.

Keywords: LC^3; Recycled Carbon Fibres; Extrusion; Additive Manufacturing; Foamed Concrete

See full paper in the proceedings.

Effect of Acid and Cement Slurry Treatment of Recycled Aggregate on Concrete Performance

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Abstract: Concrete remains the backbone of modern construction because of its durability and cost-effectiveness. However, increasing demand and the depletion of natural aggregates have heightened sustainability concerns, especially in Nigeria, where large volumes of tested concrete cubes and construction debris are disposed of in landfills. Although recycling construction waste has great potential, the effective use of recycled coarse aggregates (RCA) in structural concrete, especially when properly treated, remains underexplored in developing regions. This study investigated the compressive strength of treated recycled coarse aggregate concrete (TRAC) compared to conventional concrete and untreated recycled aggregate concrete (URAC). The aims include quantifying the amount of usable aggregate that can be recovered from waste concrete and analyzing the effects of treating RCA with 0.1 M concentrated sulfuric acid (H_2SO_4) and a cement slurry on physical properties. Discarded concrete cubes and cylinders were crushed and sieved to produce 4–35 mm RCA. The aggregates were treated by soaking in 0.1 M H_2SO_4 and coated with a cement slurry. Three concrete mixes were prepared: TRAC, URAC, and normal concrete. Results indicated that about 78% by weight of usable coarse aggregates could be recovered from crushed waste concrete. Treatment decreased RCA water absorption from 5.2% to 2.2% and increased aggregate density from 2350 kg/m³ to 2480 kg/m³. The 28-day compressive strength tests showed that TRAC reached 24.02 MPa, outperforming URAC at 23.28 MPa and performing similarly to normal concrete at 24.23 MPa. These results showed that treated RCA can produce structural-grade concrete, providing environmental and economic benefits by reducing landfill waste and saving natural resources. The study supports SDG 12 and offers practical insights for engineers and policymakers working toward sustainable and circular construction practices.

Keywords: Recycled aggregates, compressive strength, concrete waste, circular economy, sustainable construction, SDG 12, sulfuric acid treatment, cement slurry treatment.

See full paper in the proceedings.

Utilisation of Recycled Concrete Powder to Activate Calcined Clay in LC3 Systems

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Abstract.

With diminishing supplies of traditional SCMs, there is growing interest in alternatives. Two such alternatives are calcined clays and recycled concrete powder (RCP). Blending calcined clay with limestone and clinker produces limestone calcined clay cement (LC3), where portlandite from clinker hydration reacts with silicates in the clay and limestone provides an initial filler effect and subsequent material to react with aluminates in the clay. Similarly, RCP can be a source of portlandite, calcite and aluminosilicates. This study has therefore examined the partial substitution of OPC in an LC3 system with both heated and unheated recycled concrete powder (RCP) as a novel sustainable resource. The performance of these materials has been assessed by compressive strength measurements and complemented with comprehensive characterisation by thermal analysis, XRD, FTIR. While there is some loss in strength, RCP can effectively replace some OPC in LC3 systems.

Keywords: Waste cement powder, heat treatment, compressive strength, microstructure, LC3, Calcined clay, Metakaolin.

See Full Paper in the Proceedings

Glass fiber gradients in cementitious materials: rheological challenge and validation of mechanical performance

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Abstract. Functionally graded materials (FGMs) exhibit spatial variations in composition and properties that enable tailored mechanical performance. While conventional cementitious construction materials are typically homogeneous, the development of graded structures remains challenging, particularly under structural loading. This study investigates a functionally graded fiber-reinforced cementitious material with a variable glass fiber distribution across the cross-section, produced using a Selective Paste Intrusion (SPI) additive manufacturing technique.

The objective is to achieve mechanical performance comparable to that of a homogeneous fiber-reinforced material while reducing overall fiber content. The process feasibility is assessed through rheological and penetration criteria based on a modified Darcy's law, highlighting the necessity for paste yield stress to remain below the resistance threshold of the porous medium. Experimental results from flexural tests demonstrate that functionally graded specimens, incorporating approximately half the fiber dosage, exhibit flexural strengths similar to those of conventionally cast materials. These findings confirm the potential of functionally graded cementitious materials combined with additive manufacturing techniques as a promising pathway toward more efficient and sustainable structural materials.

This study opens new perspectives for the development of functionally graded fiber-reinforced construction materials and highlights the potential of emerging 3D printing technologies in structural engineering applications.

Keywords: 3D printing, Rheological properties, Micro-reinforcement, Graded

See full paper in the proceedings.

EFFECT OF MAGNESIUM NITRATE ON THE STRENGTH AND MICROSTRUCTURE OF CEMENTLESS BINDER

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Abstract

The development of cementless binders with sufficient strength is crucial for reducing carbon emissions in construction materials. This study examines the effect of magnesium nitrate ($Mg(NO_3)_2$) on the strength and microstructure of a CaO-activated binder system. Compressive strength tests revealed that the incorporation of $Mg(NO_3)_2$ markedly enhanced mechanical performance, with an optimum dosage of 6 wt% achieving a 28-day strength close to 50 MPa. X-ray diffraction (XRD) analyses confirmed the formation of additional calcium–aluminosilicate–hydrate (C-(A)-S-H) gels, which contributed to the densification of the binder matrix. Thermogravimetry (TG) results indicated accelerated consumption of portlandite and increased production of hydration products with $Mg(NO_3)_2$ addition. Mercury intrusion porosimetry (MIP) further demonstrated a refinement of pore structure, with reduced capillary pores and lower overall porosity at the optimal $Mg(NO_3)_2$ dosage. These findings suggest that $Mg(NO_3)_2$ is an effective additive to improve both the strength and microstructural stability of CaO-activated binders, offering a promising pathway for sustainable cementless materials.

Keywords: Cementless binder, Magnesium nitrate, Compressive strength, Microstructure, Lightweight mortar

THE EFFECT OF CALCINATION TEMPERATURE AND DURATION ON PHASE ASSEMBLAGE AND REACTIVITY OF HYDRATED CEMENT PASTE

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Abstract

Partially substituting cement clinker with supplementary cementitious materials (SCMs) is an effective strategy for reducing the carbon footprint of the cement industry and mitigating climate change. However, the supply of many conventional SCMs is limited, highlighting the need for alternative sources. At the same time, rapid global urbanization generates large volumes of concrete demolition waste. Recycling technologies have been developed to process concrete demolition waste into recycled concrete aggregates and recycled concrete fines. Recycled concrete fines consist largely of hardened cement paste, which can be valorised as SCMs through thermal activation. Despite this potential, there are still several outstanding knowledge gaps: there is no consensus on the calcination parameters required to achieve optimal reactivity; most studies have focused only on strength development and so their chemical reactivity is not well known; and, the effect of calcination duration on phase assemblage is rarely quantified. This study aims to address these knowledge gaps by preparing crushed, hydrated cement paste, and calcining at various temperatures and durations. The calcined hydrated cement paste fines were analyzed regarding their phase assemblage, microstructure, and chemical reactivity using X-ray diffraction (XRD), scanning electron microscopy (SEM), and the R^3 test (via isothermal calorimetry).

The results provide insight into the relationship between calcination parameters and reactivity, supporting the determination of the most effective thermal activation conditions for hydrated cement paste. These findings hence contribute to strategies for activating recycled concrete fines for use as SCMs in cement production.

Keywords: Recycled concrete fines, Thermal activation, Calcined cement paste, Phase assemblage, Microstructure, Chemical reactivity

Ideal Solid-Solution Thermodynamic Modeling of Geopolymers Across Acidic and Alkaline Conditions

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Abstract. Metakaolin-based geopolymers are increasingly recognized as durable alternatives to Portland cement owing to their superior chemical and mechanical resilience in aggressive environments. Yet, a comprehensive thermodynamic framework for predicting their long-term stability across different pH conditions remains underdeveloped. In this study, we apply a thermodynamic modeling approach to simulate the dissolution and phase behavior of geopolymer gels over an extended pH spectrum representative of nitric acid and NaOH exposure. Model predictions were validated against published experimental datasets, with emphasis on aqueous sodium concentrations and solid–solution phase transitions in aluminosilicate gels. To address limitations in previous approaches, protonated gel and silica gel phases were introduced as essential endmembers in the proposed ideal solid-solution model. Their inclusion enables accurate representation of alkali–proton exchange processes that control sodium leaching under near-neutral to alkaline conditions, as well as the onset of dealumination under acidic attack. The model reproduces the pH-dependent release of sodium and aluminum, capturing the coupled mechanisms of alkali loss and framework destabilization. These results demonstrate the capability of ideal solid-solution N-A-S-H models to provide mechanistic insights into the chemical stability of geopolymers. Beyond fundamental understanding, the framework supports mix design optimization to enhance acid resistance and offers a predictive basis for assessing the service life of alkali-activated materials in aggressive environments.

Keywords: Thermodynamic modeling, Geopolymers, Acid Attack, Phase assemblage, Ideal solid-solution solubility models, Alkali-proton cation exchange.

See full paper in the proceedings.

Guidelines for a Round-Robin test on Timber Connections within TC TPT

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Abstract. A reliable characterisation of the response of mechanical dowel-type timber connections is essential for the development of design methods. The European standard EN 26891 and the American standard ASTM D1761 provide guidelines for the experimental tests of connections made with mechanical fasteners and have been widely adopted in research practice. However, differences in loading protocols, test set-ups, boundary conditions, and displacement measurements hinder a direct comparison between experiments, making the reliability and transferability of results difficult to assess. To address this gap, the RILEM TC TPT is developing a round-robin programme to assess the reproducibility and repeatability of tests on timber connections in accordance with EN 26891 and ASTM D1761 across various laboratories. The specific objectives of this initiative are as follows: i) identify sources of variability in testing outcomes related to equipment, operator, and procedural interpretation; ii) quantify the influence of specimen preparation and material sourcing on the evaluation of the mechanical performance of dowelled timber joints; and iii) provide a basis for improving standardisation in test methods and reporting across laboratories. The programme is structured in two phases: i) centralised material supply with Laminated Veneer Lumber to minimise material variability, focusing on the influence of specimens' assembly and test set-up, and ii) independent and local sourcing of Glued Laminated Timber to capture local material and fabrication influences. With this, the round-robin experimental campaign aims to contribute to more reliable testing procedures and to the refinement of international design standards for timber connections.

Keywords: Timber connections, Dowel-type fasteners, Round-Robin tests, Standardisation of test methods.

See full paper in the proceedings.

YIELD STRESS MODELING OF CEMENT PASTES AND MORTARS WITH HETEROGENEOUS UNCONVENTIONAL AGGREGATES DERIVED FROM WIND TURBINE BLADE WASTE

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Abstract

The determination of yield stress in cementitious materials is fundamental for both casting operations and concrete mix design. Fresh concrete exhibits a yield stress: below this threshold it behaves as a viscoelastic solid, whereas once exceeded, it flows under steady-state conditions typically described by the Bingham or Herschel-Bulkley models. With the building industry facing increasing pressure due to the depletion of natural resources, the development of alternative materials that reduce reliance on traditional binders while valorizing industrial waste has become a priority. Raw Crushed Wind Turbine Blade (RCWTB) has recently emerged as a promising additive for cementitious systems, demonstrating favorable mechanical and durability-related outcomes. Nevertheless, a comprehensive rheological characterization of RCWTB-containing mixtures, particularly with respect to yield stress, remains lacking, despite its critical relevance for practical applications. In this study, the yield stress of cementitious pastes and mortars incorporating RCWTB at two water-to-cement ratios is systematically evaluated. The results indicate that higher RCWTB incorporation leads to an increase in yield stress, primarily attributable to the bridging effect of the Glass Fiber Reinforced Polymer (GFRP) contained in RCWTB. Furthermore, a physical model is applied to predict the maximum packing fraction of GFRP fibers as a function of their geometry, elastic properties, and the rheology of the surrounding cementitious matrix. The model predictions are subsequently validated against experimental measurements of yield stress in pastes and mortars including RCWTB.

Keywords: Rheology; Maximum Packing Fraction; Raw Crushed Wind Turbine Blade; Glass Fiber Reinforced Polymer; Yield stress.

CAPILLARY ABSORPTION IN CONCRETE: A PORE-LEVEL INSIGHT

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Abstract

When a concrete specimen comes in contact with water, spontaneous imbibition occurs due to capillary suction within the concrete's interconnected pore network– a process highly relevant to corrosion-induced damage and, therefore, the durability of cement-based structures [1]. Such processes have been extensively studied at the macroscopic scale, for example, through bulk sorptivity or gravimetric absorption experiments, as well as modeled using approaches based on the Lucas–Washburn and Richards' equations [2]. However, experimental observations on real concrete often deviate from the behaviour predicted by these classical models, indicating that deeper pore-scale understanding and more refined transport models—capable of capturing the complexity of pore-scale microstructure and dynamics—are required [3].

In recent years, pore-scale imaging has emerged as a powerful tool for probing this complexity. However, advanced techniques such as X-ray CT, neutron radiography, or NMR still fall short in capturing the three-dimensional dynamics of water movement over time with sufficient spatial and temporal resolution. To address this gap, in this work, we combine pore-scale imaging with high-fidelity numerical simulations to perform virtual experiments that reveal water imbibition dynamics through the heterogeneous cement-based pore structure. The real three-dimensional microstructure of a hardened mortar specimen has been obtained by FIB-SEM imaging with sub-micron resolution [4], while detailed numerical simulations of fully resolved (air-water) multiphase flow were obtained by computational fluid dynamics (CFD) simulations [5]. These simulations provide new insight into the water transport through real cement-based microstructure, thereby advancing our fundamental understanding of the capillary absorption process.

Keywords: Moisture transport, Pore-level, Numerical modelling, Cementitious material, Microstructure imaging

Effect of Calcium on MK/GGBS Strain-Hardening Geopolymer Composites (SHGC)

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Abstract:

This study explores the influence of calcium (Ca) on the fiber-bridging behavior of Engineered Geopolymer Composites (EGC)/Strain-Hardening Geopolymer Composites (SHGC), using metakaolin (MK) and ground granulated blast furnace slag (GGBS) as precursors activated by sodium silicate and sodium hydroxide. A series of MK/GGBS blends were systematically investigated through compressive and tensile strength tests, single-fiber pull-out experiments, and matrix toughness evaluation. Microstructural characterization and thermodynamic modeling were conducted to elucidate the phase evolution and reaction mechanisms associated with varying Ca contents. The fiber-bridging constitutive model was employed to analyze how Ca, introduced via GGBS, modulates interfacial bonding and energy dissipation capacity. Results reveal that an optimal Ca dosage (10-20% GGBS) promotes hybrid N-A-S-H/C-A-S-H gel formation, enhancing fiber-matrix interaction and enabling pronounced strain-hardening behavior. These findings offer a mechanistic understanding and design guidance for optimizing Ca incorporation to achieve high-performance alkali-activated fiber-reinforced composites.

Keywords: Engineered Geopolymer Composites/Strain-hardening Geopolymer Composites (EGC/SHGC), mechanical properties, sustainability, fiber-bridging constitutive model, thermodynamic modeling

Performance of High Cement-Substitution Concretes: Effect of Limestone Filler on Chloride-Ion Permeability

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Abstract. Concrete is one of the most widely used construction materials worldwide due to its versatility and compatibility with various components. However, its production relies on limestone calcination at high temperatures, an energy-intensive process that generates significant CO_2 emissions. To mitigate this impact, a promising strategy is to partially replace cement with limestone filler while maintaining the required performance. This research evaluates the effect of replacing 7.5% to 40% of the total cement mass with limestone filler on chloride-ion permeability and compressive strength. Chloride ingress is a major cause of concrete deterioration, as chloride ions penetrate through diffusion, permeability, or capillary suction, altering the pH and disrupting the passive protective layer on the reinforcement, leading to steel oxidation and expansion. The study investigates six mixtures: two controls (100% GU cement and GUb-8SF cement with 8% silica fume) and four mixtures based on GUb-8SF with 7.5%, 15%, 25%, and 40% limestone filler substitutions. Chloride-ion permeability was assessed using the RCPT (at 91 days) and the Nordic standard method (at 91 days), complemented by compressive strength testing. Results show that increasing limestone filler content generally reduces compressive strength, except at 28 days, where the GU, GUb-8SF, and GUb-8SF-15LF (15 % limestone filler) mixes displayed similar performance. Regarding chloride-ion penetration, all mixtures exhibited a very low permeability class (100–1000 coulombs), except for the GU control mix, which showed low permeability (1000–2000 coulombs) according to ASTM C1202 at 91 days.

Keywords: Concrete, Limestone filler, SCM, Chloride ions, Performance.

See full paper in the proceedings.

EFFECTS OF ALKALINE ACTIVATOR AND SLAG CHEMISTRY ON THE SOLIDIFICATION OF Pb AND Mn IN ALKALI-ACTIVATED SLAG

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Abstract

Alkali-activated granulated blast furnace slag (AAS) is the dominant class of alkali-activated materials in large-scale production of concrete applications. However, the availability of its precursor is largely dependent on geographical location and especially becoming limited in some regions due to policy changes related to the green transition of the iron-steel industry, which consequently impedes the commercial scale deployment of AAS. To deal with this issue, researchers are searching for alternative metallurgical slags with potential reactivity, such as ferronickel slag, lead-zinc slag and copper slag, etc. These slags are massively discharged annually worldwide, not only occupying much land but also seriously polluting nearby soil and water. Utilizing these metallurgical slags to synthesise AAS would be an efficient and high-value-added solution to the aforementioned two problems. Although many efforts have been made, their current utilization is still restricted due to the high concentrations of heavy metals (HMs) in these metallurgical slags, such as Cr, Pb, Mn and As, etc. In-situ immobilization of HMs via solidification/stabilization in metallurgical slag-based AAS could be a sustainable and cost-effective solution, provided that the immobilization performance of AAS is clear. Against this background, we investigate the solidification of Pb and Mn in alkali-activated slag with different mixture formulations. The solidification capacity is determined and discussed in terms of physical adsorption and chemical binding. The effects of alkaline activator and slag chemistry on the solidification behaviour are to be elucidated with the aid of microscale analysis, such as XRD and FTIR, etc. Moreover, the solidification performance with respect to time is evaluated via the extraction toxicity test. The samples have been prepared and tests are in progress. The results are expected to be presented during the conference.

Keywords: alkali-activated slag, heavy metals, solidification, physical adsorption, chemical binding, extraction toxicity

FRESH STATE PROPERTIES OF ALKALI-ACTIVATED SLAG MORTARS INCORPORATING WOOD BIOMASS FLY ASH

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Abstract

This study investigates the fresh-state behavior of alkali-activated slag mortars incorporating wood biomass fly ash (BFA) as a partial precursor replacement. A Taguchi L_9 orthogonal array was employed to evaluate the influence of four mix parameters: water-to-precursor (W/P) ratio (0.42–0.50), BFA content (15–45 wt.%), silicate modulus (Ms = 0.5–1.4), and Na_2O dosage (3.5–5.5 wt.%), on the workability of mortars. Mini-slump and flow tests were measured to determine consistency and flowability in accordance with EN 1015-3. The results show that the W/P ratio had the most significant influence on workability, followed by silicate modulus, Na_2O content, and BFA dosage. Higher W/P ratios and Ms values enhanced flowability due to improved dissolution of solid precursors and lower interparticle friction, whereas elevated Na_2O contents increased solution viscosity, reducing slump and flow. BFA incorporation up to 30 wt.% improved workability, while further addition to 45 wt.% decreased it, mainly due to increased water demand associated with fine BFA particles. Mixtures within the ranges W/P = 0.45–0.50 achieved plastic-to-fluid consistencies, producing slump values up to 20 mm and flow diameters around 205 mm. Overall, the results confirm that wood biomass fly ash can be effectively incorporated in alkali-activated slag mortars without compromising fresh-state performance when mix parameters are optimized. These findings provide valuable guidance for designing workable, sustainable, and low-carbon alkali-activated binder systems.

Keywords: Alkali-activated mortar, Wood biomass fly ash, Ground granulated blast furnace slag

SIGNIFICANCE OF PROPER SULFATE ADJUSTMENT IN HYBRID BINDERS

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Abstract

Reducing clinker content in cement is essential for lowering CO_2 emissions, driving interest in supplementary cementitious materials (SCMs) such as calcined clays and volcanic pozzolanas. While alkali activation can improve early-age performance in low-clinker systems, the combined effects of alkali content, sulfate dosage, and SCM type remain insufficiently understood. This study investigates ternary hybrid binders with clinker contents below 30%, using two SCM systems: alumina-rich calcined clay and silica-rich natural pozzolana, both blended with limestone. Three alkali activators, namely sodium sulfate, sodium carbonate, and sodium metasilicate, have been evaluated. Compressive strength has been measured across varying alkali activators and sulfate adjustment combinations after 2 days and 28 days of hydration to explore their interdependent effects. In terms of mechanical performance, multiple activator dosages have been tested to deliver alkali equivalents of 1%, 1.5% and 2%, however microstructural characterization analysis has been done mainly at alkali equivalent of 1.5%. Hydration kinetics and phase evolution were interpreted using calorimetry and X-ray diffraction, offering deeper insight into factors governing strength development. Results show that sulfate adjustment must be tailored to alkali content to avoid delayed reactions or suppressed strength gain. Sodium carbonate, in particular, can exhibit multi-day induction periods if sulfate is insufficient. Secondary phase formation, including hemicarbonate and monocarbonate, depends strongly on both alkali and sulfate availability. The effectiveness of sodium sulfate was sensitive to handling: dry mixing followed by storage led to partial prehydration and reduced hydration efficiency, whereas pre-dissolution or casting within 24 hours restored performance. The findings highlight that volcanic pozzolana and calcined clay respond differently to sulfate balance depending on the presence of activators. This study provides insight into optimizing sulfate and alkali activation strategies for hybrid binders and contributes to the design of more sustainable and high-performance cementitious systems.

Keywords: Hybrid binders, Low-clinker cement, Alkali activation, Sulfate adjustment

VALORIZATION OF LOW-GRADE LIMESTONE FOR SUSTAINABLE CONCRETE AND EXTENDED QUARRY RESERVE LIFE

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Abstract

This study evaluates the feasibility of using low-grade limestone commonly rejected for clinker production, in both binary Portland Limestone Cement (PLC) blends and ternary Limestone Calcined Clay Cement (LC3) systems. Three representative low-grade limestones with varying silica, clay, and magnesium contents were assessed. For the binary cementitious systems, Ordinary Portland Cement (OPC) was partially replaced with low-grade limestone at replacement levels of 5%, 15%, 35%, and 50% to establish performance thresholds and to evaluate the maximum feasible limestone content that can be incorporated while still maintaining structural-grade behaviour. For ternary LC3 systems, calcined clay and low-grade limestone were combined at clay: limestone mass ratios of 2:1 and 1:1 to achieve a total clinker substitution of 50%. Fresh properties (workability, slump retention, and superplasticizer demand), compressive strength development, and key durability metrics (surface electrical resistivity, chloride migration coefficients, and carbonation resistance) were measured. Binary blends with up to 15% low-grade limestone matched conventional PLC performance, while higher binary replacement levels showed expected dilution effects, mitigated partially by filler and nucleation benefits. LC3 mixtures incorporating low-grade limestone exhibited fresh and hardened concrete performance equivalent to reference LC3 produced with cement-grade limestone. These results demonstrate that low-grade limestone can be effectively utilized in both PLC and LC3 formulations, offering a practical route to broaden raw material use and reduce clinker consumption.

Keywords: Supplementary cementitious material, low-grade Limestone, Portland limestone cement, Limestone calcined clay cement, Chloride resistance, Carbonation resistance, Sustainability

PERSPECTIVES ON DURABILITY DESIGN FOR LOW CARBON BINDER SYSTEMS

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Abstract

The world over, it is accepted that sustainability in concrete construction can primarily be brought about by using less concrete through innovative design practices, using less cementitious binder in concrete, and finally, using less clinker within the cement. However, while doing so, it is also important to ascertain that the concrete can be designed to suitably meet the demands of service in the intended environment. The use of low clinker systems for concrete often creates some challenges with respect to durability design, which are primarily caused by the interplay between pore structure and chemistry. For instance, the performance in a chloride environment, which is dominated by pore structure, is usually better for low clinker systems, while the lack of sufficient alkaline buffer causes the carbonation resistance to be poorer. Another example could be the positive performance in leaching and possible negative performance in types of acid attack that create insoluble products. This paper explores the possibilities for durability design of concrete with low clinker binders in different exposure conditions. The paper explores different durability scenarios, and suggests the use of a combination of durability parameters that relate to both the chemistry and the pore structure, along with suitable utilization of additional protective measures in situations where the performance is expected to be poorer with low clinker systems. Further, the adoption of suitable Life Cycle Assessment techniques that combine the performance characteristics (i.e. strength and durability) with the CO_2 emission and energy utilization can prove better to handle the material selection for durable concrete construction.

Keywords: Supplementary cementitious material, Low-clinker binder, Durability, Life Cycle Assessment, Sustainability

REPURPOSING WASTE CONCRETE FINES IN BINDERS FOR ADDITIVE MANUFACTURING OF CONCRETE

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Abstract

This study focuses on developing low-carbon cementitious systems by valorising waste concrete fines (WCF), a by-product generated during concrete recycling, as alternative binder for 3D printed concrete. An integrated approach combining carbonation chemistry and rheological evaluation was adopted to engineer novel materials capable of performing a dual function: as a binder and a medium for CO_2 storage. WCF sourced from laboratory-controlled processes (thermomechanical beneficiation, mechanical crushing, and mortar recycling) and field-scale operations (demolished metro rail pile cap and commercial crushing facility) were investigated to capture the full variability of practical recycling routes.

Results showed that WCF derived from different aggregate production processes exhibited CO_2 uptake ranging from 4.9% to 18.2% by mass, depending on composition and grain size. This sequestration capacity could potentially offset 10% to 28% of the net carbon footprint associated with concrete production.

Following mineralisation, both uncarbonated (UWCF) and carbonated (CWCF) WCF were incorporated into OPC and Limestone Calcined Clay (LC_2) based 3DPC at various replacement levels to assess rheological, hydration, mechanical, and durability performance. The study found that carbonation improved printability and hydration, leading to higher strength, and reduced porosity. Optimal performance was achieved at 30–50% CWCF replacement, demonstrating that CO_2-mineralised WCF can function as a low carbon binder, effectively sequestering CO_2 and reducing the 3DPC carbon footprint

Keywords: Waste concrete fines; 3D printable concrete; rheology; sustainability; sequestration

TOWARD ONE-PART ALKALI-ACTIVATED METAKAOLIN VIA INTER-GRINDING: ASSESSING RHEOLOGY AND REACTION MECHANISM

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Abstract

Developing alkali-activated materials (AAMs) is one of the pathways to decarbonize cement manufacturing that currently contributes 5-8% of global anthropogenic carbon emissions. However, extensive deployment of AAMs in industry has yet to be realized, part of which is likely due to the reluctance to work with "two-part" activation that requires handling large amounts of concentrated caustic solutions. Here, we have developed a "one-part" AAM, where the dry mixture of precursor and solid activator (dry mix) is combined with only water, resembling the hydration of OPC. The dry mix is prepared through inter-grinding, which is explored for its known potential of altering physicochemical properties of the powders and for the practical advantage of utilizing existing cement infrastructure. 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. It is shown that inter-grinding causes a broadening of particle size distribution, which results in significantly improved rheological behavior. Other physicochemical properties such as the evolution of micro- and nano-structure are explored to elucidate the effect of inter-grinding on the kinetics and extent of reaction.

Keywords: One-part alkali-activated materials, calcined clay, grinding.



PROCESSESS:

mixing

pumping

casting

3D printing

3D Printability of autogenous self-healing lime-cement mortars

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Abstract. Durability of 3D printing cement-based construction still needs to be investigated. On one hand, the large amount of paste phase, the low w/c ratio of printable mortars and the high exposed surface of 3D printed specimens to environmental conditions, due to the absence of formworks, lead to high early age shrinkage and cracking risk. On the other hand, poor bonding between 3DP layers can produce cold joints that could compromise 3D printed members' strength and durability. This study investigates the adaptability of self-healing strategies for 3DP cement-based construction requirements. A lime-cement binder, 1:1 volumetric ratio, was designed to generate autogenous self-healing capacity. Besides, cellulose microfibres (CMF) were added to increase tensile strength, restraining crack size. Then, a Superabsorbent Polymer (SAP) was used to provide water retention capacity, acting as an internal curing agent, in order to reduce early age shrinkage. Mortars' printability was assessed by rheology and extrudability tests. Mixtures' buildability was evaluated by fresh compression tests and by monitoring early age hydration with ultrasonic non-destructive techniques. A robotic-arm 3D printer was used to produce lab scale specimens for a comprehensive evaluation of the printing process. The conclusions of this study could shed light on the design of low-cement-content mortars with self-healing capacity for 3D Printing applications.

Keywords: 3D Printing; Lime-cement Mortars; Fiber Reinforcement; Superabsorbent Polymer; Printability; Self-healing.

See Full Paper in the Proceedings

Manufacture and load-bearing capacity of cap ceilings in 3D concrete printing

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Abstract. Vaulted cap ceilings represent architecturally and structurally sophisticated constructions commonly found in historic buildings. However, they are rarely used in contemporary construction due to high manufacturing costs, complex formwork processes, and limited compatibility with modern industrial construction processes. This paper investigates the potential of 3D concrete printing as an innovative manufacturing process that combines the traditional design of vaulted ceilings with the need for cost-effectiveness, sustainability and prefabrication. Inspired by historical vaulted ceilings, curved load-bearing structures have been developed that can be manufactured using an additive fabrication process and installed between primary supporting structures. Parametric design and computational analysis methods were employed throughout the process to enhance material efficiency and structural performance. In addition to automating construction processes, 3D printing enables the formwork free production of complex geometries and targeted material placement. The result is load-bearing structures with high load-bearing capacity and minimal use of materials. This makes it possible to economically implement curved load-bearing structures. Physical prototypes of the developed systems were manufactured and subjected to mechanical testing to assess their load-bearing behaviour. The experimental data shows strong agreement with numerical stress simulations, confirming the predictive accuracy of the digital models. The results highlight the high structural efficiency, dimensional stability and mechanical reliability of the proposed systems. Beyond structural performance, the environmental impact is significantly reduced. By minimizing material usage and eliminating the need for conventional reinforcement, CO_2 emissions are substantially lower than those of traditional concrete ceiling systems. The integration of digital design and automated fabrication processes establishes vaulted cap ceilings as a viable, resource- efficient and architecturally expressive sustainable construction solution.

Keywords: 3D-printing, concrete, cap ceilings, additive manufacturing, carbon efficiency, stress-driven design

See Full Paper in the Proceedings

PREDICTING FILAMENT GEOMETRY IN 3D CONCRETE PRINTING VIA NUMERICAL SIMULATION AND MACHINE LEARNING

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Abstract

In 3D Concrete Printing (3DCP), the quality of the printed elements critically depends on accurate material extrusion and layer deposition. This work presents an integrated numerical-machine learning framework for investigating and predicting filament geometry from material and process parameters.

The study builds on the Particle Finite Element Method (PFEM), which combines an updated Lagrangian finite element formulation with an efficient remeshing strategy, allowing accurate modelling of evolving free surfaces and large deformations. PFEM has previously been used by the authors to simulate extrusion and deposition in 3DCP, modelling fresh concrete as a viscoplastic Bingham fluid (Rizzieri et al. 2023). After extensive validation against experiments, PFEM was employed to simulate a broad set of rectilinear single- and two-layer printing scenarios, systematically varying yield stress, viscosity, nozzle geometry, layer height, and extrusion/translation velocities. Simulations revealed distinct deposition regimes, including quasi-Newtonian flow, free-flow deposition with rounded or spread filaments, filament tearing, and layer pressing, and enabled the generation of a prototype design chart for filament shape prediction (Rizzieri et al. 2025). Nonetheless, despite its informative nature, the chart remains limited to free-flow deposition and offers limited predictive capability on the actual layer's shape.

To overcome these limitations, we have developed ShapeGen3DCP (online version available through https://www.dica.polimi.it/ai3dcp), a deep learning framework for layer shape prediction in 3DCP trained on a synthetic PFEM-generated dataset. Input parameters are reformulated into dimensionless groups, while output filament profiles are approximated with Fourier descriptors, reducing prediction to a small set of coefficients and ensuring smooth, symmetric profiles. Validation against numerical and experimental data confirms high accuracy. Overall, ShapeGen3DCP provides a fast alternative to costly simulations, enabling toolpath optimization, design exploration, and reduced trial-and-error, while laying the foundation for real-time sensor integration, supporting closed-loop digital twins for additive manufacturing in construction.

Keywords: 3D Concrete Printing (3DCP); Extrusion flow regimes; Filament geometry prediction; Particle Finite Element Method (PFEM); Numerical simulation; Deep learning.

Interplay of particle shape and size distribution on the angle of repose in secondary sands

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Abstract. The geometrical characteristics of recycled sands, particularly particle shape and particle size distribution (PSD), strongly influence their interparticle friction, packing behaviour, and suitability for construction applications such as screeds and concrete mixes. This study explores the relationship between the particle shape and PSD resulting from the manufacturing process and the internal angle of repose (AoR), a proxy for granular flowability and interparticle friction, in secondary sands derived from construction and demolition waste.

Particle shape was analysed using digital methods (laser diffractometry for the finest fractions and image analysis for large particles). The results reveal that the angle of repose is governed by a complex combination of effects from the particle shape, surface texture, and fines content. While particle angularity is considered a significant drawback of secondary manufactured sands in applications such as production of screed, mortar and concrete, the surface roughness and content of fines emerged as the primary challenges to address.

The angle of repose offers a practical metric for assessing recycled sands, but its significant variability, particularly in heterogeneous waste streams, highlights its limitations as a standalone indicator of interparticle behaviour. The study underscores the need for integrated morphological and granulometric characterization to reliably evaluate secondary sands for high-value applications.

Keywords: Recycled Sands, Angle of Repose, Roundness, Circularity, Image Analysis.

See full paper in the Proceedings

Preliminary Results on the Influence of Recycled Concrete Aggregates in 3D Printed Mortars.

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Abstract

This experimental research addresses the performance of mixes developed with II/A-S 52.5 cement and recycled concrete aggregates (RCA) oriented to applications in additive manufacturing construction. Natural aggregates (NA) were replaced by RCA in different percentages (25%, 50%, 75% and 100%) in conventional and high-strength mortars. Workability was evaluated by means of flow and settlement tests. The results showed that the produced mortars with different replacement levels of NA by RAC exhibited reduced workability. This adverse effect was mitigated by increasing the superplasticizer dosage.

Standard prismatic specimens and 3D-printed specimens were produced for characterizing the mechanical and the drying shrinkage properties.

The results proved that increasing RCA content systematically reduced workability due to higher water absorption and surface roughness, although this effect was successfully mitigated by adjusting the superplasticizer dosage. The incorporation of RCA led to moderate strength reductions -up to 20% and 24% in conventional and high-performance mixes, respectively- yet compressive strengths above 50 MPa and 70 MPa were still achieved at 28 days, confirming the mechanical viability of these mixtures for 3D printing applications.

In printed specimens, the Z-direction compressive strength (43–72 MPa) exhibited an expected anisotropy compared to molded samples, while shrinkage remained acceptable up to 75% RCA substitution but increased significantly at full replacement. Overall, the findings validate the technical feasibility of producing 3D printable mortars with RCA, highlighting their potential to reduce environmental impact without compromising performance.

Keywords: II/A-S 52.5 R Cement, 3D printing, fine recycled aggregates, slump test, flow test.

See full Paper in the Proceedings

COUPLED HYGRO-THERMO-CHEMICAL MODELING OF LAYERED CONCRETE IN 3D PRINTING FOR PROCESS OPTIMIZATION

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Abstract

With more automation and less waste, 3D concrete printing (3DCP), a new construction method, has the potential to completely transform building operations. The broad use of printed concrete is, however, constrained by the absence of trustworthy prediction models for its early-age behaviour. Layer-by-layer deposition, which is a feature of 3DCP, presents challenges with changing mechanical characteristics, heat production, and moisture loss that have a significant impact on the longevity and performance of structures. By combining mechanical response with hygro-thermal-chemical (HTC) processes, this study offers a Multiphysics finite element framework that models the time-dependent behaviour of early-age printed concrete. To accurately depict stiffness and strength development, the model incorporates a maturity-based hydration kinetics approach that is calibrated against calorimetric data. Eigenstrain formulations capture important early-age mechanisms like drying, autogenous shrinkage, and thermal expansion. A penalty-based contact formulation in conjunction with a deposition strategy that gradually activates new layers is used to model interlayer bonding and load transfer. The impact of printing parameters, such as printing speed, interlayer time intervals, and environmental conditions, on stress development and cracking risk at layer interfaces is investigated in preliminary simulations. By reducing early-age cracking and material waste, this predictive tool provides insights into process optimisation targeted at enhancing the sustainability and durability of 3D printed structures. In order to support the development of resilient and sustainable construction technologies, future work will include experimental validation and expanding the framework to model long-term durability and lifecycle performance.

Keywords: 3D Concrete Printing (3DCP), Early-Age Behaviour, Multiphysics Finite Element Modelling, Hygro-Thermal-Chemical Processes, Interlayer Bonding, Sustainability and Durability.

BOND ASSESSMENT AND ENHANCEMENT OF 3D PRINTED–CAST CONCRETE INTERFACES

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Abstract

A big challenge to be overcome for the structural application of extrusion-based 3D printed concrete is the integration of reinforcement. A possible solution for this problem is to resort to hybrid beam structures, in which a prefabricated traditionally reinforced cast component is combined with a structurally efficient unreinforced 3D printed component with a complex geometry. However, for this approach to be viable, the bond between the printed and cast concrete should be sufficiently strong in order not to be critical to the structural capacity of the hybrid beam. Once a critical interface shear strength value is obtained, the failure mechanism shifts from interface shear failure to vertical shear failure of the unreinforced 3D printed component. In the current work, the shear bond strength, which will govern in this hybrid composite beam application, is assessed for this specific combination of printing and casting. This is done through small-scale three-point bending tests, which are both representative for the final beam application and have the advantage of their smaller scale. After a reference value for the interface shear strength is established, in which no specific treatment is applied to the interface, methods to enhance the bond strength are proposed and investigated. These methods include altering the roughness of the cast component's top surface, changing the moisture state of the interface before printing, and adding inter-layer reinforcement. The experimental results show, firstly, the applicability of the small-scale beam test to assess the interface capacity, and secondly, the potential for improvement of the interface shear strength with only limited changes to the process.

Keywords: 3D concrete printing, bond strength, interface shear, hybrid systems, composite beams, additive manufacturing

Rheological Behaviour of 3D-Printable Ultra-low-carbon Concrete Recipes

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Abstract. Understanding time-dependent rheological behaviour is essential for extrusion-based 3D concrete printing, as it governs structuration and early-age strength development. However, limited data exists for cement-free mortars based on non-activated industrial slags, whose behaviour differs fundamentally from conventional cementitious systems. This work explores time-dependent rheological behaviour of fully cement-free concrete mixes tailored for extrusion-based 3D printing. The studied formulations are based on stainless steel slags as both binder and fine aggregates, with no hydraulic or alkali activation but mineral carbonation. Industrial additives are incorporated to optimize flowability, while maintaining low water-to-binder ratios to achieve a pore structure that facilitates CO_2 diffusion. Strength development is achieved exclusively through post-printing mineral carbonation under controlled temperature and relative humidity conditions in a carbonation closet. To understand the rheological behaviour crucial to 3D printing, flow table tests were used to monitor open time for extrudability, while green strength evolution was assessed using a slow penetration test. Both tests were performed at 15-minute intervals up to 60 minutes, and were used to assess the critical print height that can be achieved for the investigated mix. Results show a progressive reduction in flow value and a non-linear increase in green strength, depicting structuration governed by particle-particle interactions and moisture redistribution. These findings inform process control for 3D printing of ultra-low-carbon, cement-free concrete recipes that enable CO_2 sequestration while valorising industrial by-products.

Keywords: Slag, Rheology, 3D-printing, Carbonation, Ultra-low-carbon.

See Full Paper in the Proceedings.

Real-Time Prediction of Mixing Torque Using Deep Learning

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Abstract. Mixing torque reflects the interaction between the mixer and fresh mortar, providing insights into material consistency. Traditionally, obtaining torque measurements requires specialised sensors integrated into mixers, which adds cost and limits their practicality for large-scale or on-site use. To address this, this study proposes a deep learning framework that predicts real-time torque values directly from mixing videos. Instead of relying on specialised sensors or equipment, the model extracts spatial and temporal features from consecutive video frames using a time-series architecture. Specifically, a hybrid ResNet–LSTM model is employed: ResNet encodes spatial features from each individual frame, while the LSTM captures temporal dependencies across sequences of frames. This allows the model to learn how visual changes in the mixing process correlate with the evolving torque. A dataset comprising 21 mortar mixtures with varying compositions was collected, including synchronised video footage and torque measurements recorded throughout the mixing period. Workability, flexural and compressive strength tests were performed after mixing. The model achieved R^2 scores of 0.992 (training), 0.989 (validation), and 0.936 (testing), indicating that the model achieved high accuracy with strong generalisation ability across unseen data. The inference time is under 60 milliseconds per 5-frame sequence. The proposed method enables fast, non-contact, and reliable torque estimation, offering a practical solution for intelligent monitoring of mixing processes in real-world settings.

Keywords: Mortar workability, Artificial intelligence, Quality control, Data fusion, Real-time monitoring

See Full Paper in the Proceedings.

Shear Performance of 3D-Printed Concrete Interfaces: A Comparative Study of Horizontal and Vertical Joints

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Abstract:
As 3D-printed concrete (3DPC) advances toward structural-scale applications, the performance of interlayer interfaces remains a critical challenge. This work investigates the shear behavior of both horizontal and vertical joints in 3DPC through a series of customized push-off tests. A novel triplet specimen configuration was developed to evaluate horizontal interfaces between printed layers, incorporating both monolithically cast and 3D-printed specimens. In parallel, S-shaped specimens were used to simulate vertical joints between, e.g, 3D-printed layers printed in parallel. The experimental campaign assessed nominal interfacial shear strength, crack development, and failure modes. Crack propagation and peak stress behavior were used to characterize interfacial integrity across configurations. For the horizontal joints, 3D-printed triplet specimens achieved an average shear stress of 7.8 MPa, representing approximately 52% of the strength of the monolithically cast references (14.9 MPa). In contrast, S-shaped specimens—representing vertical interfaces—reached an average of 2.9 MPa, corresponding to only 19% of the cast reference and 37% of the 3D-printed triplets. All S-shaped specimens failed through diagonal interlayer cracking, confirming the anisotropic behavior of 3D-printed concrete and highlighting the challenges of shear transfer in vertically layered segments. These findings emphasize the importance of interface orientation and construction sequence. The proposed test configurations provide a robust framework for evaluating interlayer performance and demonstrate how process tuning can improve the structural reliability of modular 3D-printed systems.

Keywords: 3D-Printed Concrete (3DPC), Interlayer Bonding, Push-Off Test, Triplet Specimens, Interface Performance.

See full paper in the proceedings.

Optimization and Performance Evaluation of 3D Printable Concrete Ink using Recycled Coarse Aggregates from Construction Waste

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Abstract. This study investigates the optimization of recycled coarse aggregate (RCA) in 3D concrete printable ink by partially replacing natural coarse aggregates in 20% increments from 0% to 100%. The recycled concrete aggregate (RCA) was characterized for its morphological and physical properties. The rheological parameters of the ink such as viscosity, yield stress, and thixotropy were evaluated. Furthermore, extrudability, printability, and shape retention were assessed to determine the 3D printing performance of the ink. Mechanical performance was determined through compressive, flexural, and ultrasonic pulse velocity (UPV) tests. Durability was assessed using the Rapid Chloride Penetration Test (RCPT) and water absorption. Characterization results showed that the processed aggregates had a predominantly spherical morphology, enhancing the workability of the 3DCP ink. The study identified a yield stress range of 1.5–2.5 kPa as the optimal printability window, ensuring a balance between pumpability and buildability in 3D printable inks. At 40% RCA replacement, the ink achieved 82.76% structural recovery in thixotropy, indicating superior shape stability after shear, along with an open time of 60 minutes. The 28-day compressive strength of inks with 40% RCA and 40% RFA showed increases of 17.08% and 17.17%, respectively, compared to the control ink attributed to improved particle packing. Furthermore, the RCPT charge passed was significantly lower at this replacement level, indicating reduced chloride ion permeability. Overall, the findings establish 40% RCA replacement as the optimal proportion, providing an effective balance of rheological behavior, mechanical performance, durability, and microstructural refinement for 3D printable concrete applications.

Keywords: 3D Concrete Printing, Construction Waste, Recycled Coarse Aggregate, Rheology, Mechanical properties

See full paper in the proceedings.

Powder Bed 3D Printing Systems: Influence of Waveform Parameters on Jetting Behaviour and Ejection Stability

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Abstract. Powder bed 3D printing technology enables the fabrication of complex geometries with high precision. Its ability to produce both structural and functional elements relies on tailored binder liquid and precise control of binder ejection from the print head. Binder jetting print heads are equipped with piezoelectric actuators and membranes, where a piezoelectric signal drives membrane motion to eject droplets through the nozzle. The ejection process is governed by the binder's physical properties in combination with waveform parameters defined by the user.

This study presents a systematic development of binder liquids aimed at achieving precise deposition and high-quality printing. To optimize jetting behavior and ejection stability, carefully designed waveforms are essential. Liquid binders with varying surface tension and viscosity were tested under different waveform configurations. Each binder, characterized by its unique physical properties, was evaluated for droplet formation behavior under specific waveform settings. Key parameters such as pulse velocity, pulse voltage, pulse spacing, frequency, and membrane actuation timing were thoroughly analyzed.

The findings provide insights into effective waveform tuning strategies for stable and consistent droplet generation. This understanding supports the advancement of binder liquid formulations and print head operations, ultimately contributing to improved precision and reliability in powder bed 3D printing.

Keywords: Powder bed 3D concrete printing, liquid binder physical properties, waveform optimization, jetting stability, print head dynamics.

See full paper in the proceedings.

DATA-DRIVEN PROCESS CONTROL FOR CONCRETE PUMPING: FROM MONITORING TO PREDICTIVE INTERVENTION

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Abstract

Production, transport, and placement of fresh concrete remain fragmented operations, with limited continuity of data and control across stages, in present-day construction industry. While advancements in sensor technology have enabled the monitoring of individual processes such as mixing or pumping, these different stages are more than often monitored isolated from each other. Modern embedded computing enables on-edge analysis, essential for complex, localized, and proactive control strategies. Although key opportunities for optimization and early anomaly detection in concrete production are often missed, the required technologies already exist. Leveraging them for effective assistance systems is increasingly important given the growing shortage of skilled labor.

This contribution investigates how end-to-end integration of modular, real-time systems, from batching to transport and placement, can create new opportunities for making concrete construction faster, safer, more cost-effective, and environmentally sustainable. Sensor modules, edge computing devices, and machine-integrated data channels form the backbone of such systems. The approach focuses on acquiring and analyzing high-frequency signals such as hydraulic pressure, piston motion, and drum rotation, combined with environmental and mix-specific parameters, to derive actionable indicators of concrete behavior.

We analyze hydraulic pressure signals during the pumping process as a potential source of process-relevant information. By examining the time-dependent behavior of these signals, characteristic patterns related to piston strokes, flow irregularities, and pump dynamics can be identified. These observations suggest that the pumping process itself can be treated as a form of indirect measurement, offering valuable insights into the behavior of fresh concrete during placement. Field recordings from typical pumping operations illustrate how signal evolution over time reflects changing flow conditions. While no direct control interventions are proposed at this stage, the findings indicate a promising foundation for the development of future assistance systems, particularly in contexts where manual oversight is limited or skilled operators are scarce.

Keywords: Concrete Pumping, Process Monitoring, Assistance Systems, Edge Computing, Inline Quality Control.

RECYCLED CERAMIC AS SUPPLEMENTARY CEMENTITIOUS MATERIALS FOR 3D PRINTING APPLICATIONS

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Abstract

This study investigates the use of ceramic waste—an environmental and disposal challenge—as supplementary cementitious material (SCM), with the aim of reducing the carbon footprint of Ordinary Portland Cement (OPC) and promoting circular economy practices, particularly in the context of digital manufacturing. The project focuses on the development of low-carbon cementitious composites by incorporating wastes from the ceramic industry as replacement for calcined clay in limestone-calcined clay cement (LC3). This cement formulation enables a CO_2 reduction of over 40% compared to OPC.

A range of ceramic waste powders from different sources were collected and characterized. These recycled powders were subsequently incorporated into LC3 mortar. The fresh properties of the mixes were assessed using standard flow table tests alongside a ball measuring system implemented at the rheometer scale. This tool enables testing of mortars with aggregates up to 2 mm and high yield stress (kPa), representing a significant advantage over classical rheometer geometries that cannot accommodate such coarse or stiff materials. Key rheological parameters—including viscosity, static yield stress, and its evolution during the first 60 minutes of hydration—were quantified. These values were then used to calibrate a viscoplastic Bingham model, enabling a more accurate representation of the material's behaviour under shear.

To explore potential 3D printing applications, the Particle Finite Element Method (PFEM) model developed by G. Rizzieri et al. (2024) was applied to simulate the virtual printing of multi-layer walls with the designed mixes. The numerically generated cross-sections of printed structures were analysed to establish a preliminary correlation between the deformation of printed layers and the buildability characteristics of each composition. Proof-of-concept trials were conducted on real samples.

This approach shows that ceramic waste can be valorised in sustainable construction, reducing landfill and CO_2 emissions while supporting advanced material design for additive manufacturing.

Keywords: recycled ceramic, Limestone Calcined Clay Cement, 3D printing, numerical modelling, rheology.

Effects of bio-based components on rheology and printability of low cement-based 3d printable mortars

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Abstract. 3D printing technology with cement-based mortars is an opportunity for innovative architectural construction. However, 3D-printable mixtures require changes in their composition to become a sustainable solution, such as a remarkable reduction of cement content and the use of bio-based components (BBC). BBC are a renewable resource and have huge potential to improve sustainability of cement-based systems while offering other excellent material properties such as reinforcement, lightweight, water absorption, thermal insulation, etc. An experimental study on the effects of three different bio-based components on rheology and printability using a low-cement-based mortar was carried out. A reference Cement - limestone filler (LF) mortar (R), 1:1 cement-to-LF ratio, 0.4 water-to-binder ratio, 1.5:1 sand-to-binder ratio, and a functionalized attapulgite as a rheology modifier, was designed. Then, three BBC were incorporated: a biomass ash at 10% of LF volume, a microencapsulated Bio-based Phase change material (B-PCM) at 20% of mortar volume, and a cellulose fiber (CF) at 7.5% of mortar volume. Also, a mixture containing all bio-components was also assessed. A target 3D printable initial consistency was achieved using a commercial Superplasticizer (SP). Rheological parameters were evaluated using different laboratory and field oriented experimental methods, including DSR, a fast cone-penetrometer test, ram extrusion test, and squeeze test. Printability was assessed using a 3D robotic arm printer. While all samples were 3D printable, those samples with BA and CF showed water segregation and more defects during filament deposition. On the other hand, R and B-PCM showed initial low extrusion force and good cohesion which produced proper printability, while increased shear yield stress over time (effective thixotropy), enhancing buildability. Conversely, BA and CF showed lower effective thixotropy.

Keywords: Bio-based components, 3D printing, limestone filler, rheology, printability.

See full paper in the proceedings.

BIO-INSPIRED STRUCTURAL DESIGN AND 3D PRINTING OF STRAIN-HARDENING CEMENTITIOUS COMPOSITES (3DP-SHCC)

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Abstract

Natural biological structures, owing to their exceptional performance, have served as a source of inspiration for the development of advanced artificial materials. However, their complexity often surpasses the capabilities of traditional manufacturing methods. The high design flexibility of 3D concrete printing (3DCP) makes it a promising technique for the fabrication of bio-inspired structures. Strain-hardening/engineered cementitious composites (SHCC/ECC), known for their superior strength, ductility, toughness, and durability, are suitable for 3DCP applications. In this study, inspired by the dactyl club of *Mantis shrimp*, we developed 3D printed SHCC with Bouligand structures. 3D printed SHCC with Bouligand structures significantly enhances flexural strength and toughness while reducing anisotropy, thereby improving structural integrity through the crack-twisting and bridging mechanisms induced by the Bouligand structures. Inspired by the diving bell of *Argyroneta aquatica*, we developed a 3D printed SHCC reticulated shell roof that exhibits high ductility, low weight, and high energy absorption. We further proposed and validated the construction of an almost fully automated building with this bio-inspired 3D printed SHCC reticulated shell roof. This approach significantly reduces manual labor and increases construction efficiency, making it suitable for rapid construction in extreme environments. Additionally, inspired by the slender stems of *Elytrigia repens*, we developed a bio-inspired 3D printed SHCC porous lattice structure. This structure has been optimized at both the micro- and macroscales, to enhance lightweight construction, material efficiency, and cost-effectiveness, without compromising mechanical performance. Potential applications of this structure include building facades, which provide both aesthetic appeal and material efficiency, and partition walls that offer excellent thermal insulation and soundproofing. This study provides both a theoretical foundation and practical insights into the development of bio-inspired 3D printed concrete structures for future architectural and engineering applications.

Keywords: 3D concrete printing; Strain-hardening/engineered cementitious composites (SHCC/ECC); Bio-inspired; Bouligand structure; Reticulated shell structure; Porous lattice structure.

Preliminary experimental investigation on the material properties of a lightweight foamed concrete via 3D printing

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Abstract. The integration of Foamed Concrete (FC) in 3D Concrete Printing (3DCP) processes represents a promising and forward-thinking strategy within the construction sector. This approach aims to combine the unique advantages of FC – such as lightweight nature, enhanced sustainability, and multifunctionality – with the efficiency and precision offered by automated construction technologies.

Despite its potential, the use of FC in 3DCP remains largely underexplored due to the additional challenges posed by the distinct rheological and physical characteristics of FC, which affect printability, buildability, and ultimately the performance of hardened 3D-printed elements. Nevertheless, a deeper understanding of this research domain could facilitate the development of strategies to improve control over these factors, thereby enabling the successful use of FC in 3DCP.

The present study investigates the application of a lightweight foamed concrete with a dry density of approximately 760 kg/m³ in a medium-scale 3DCP process. Some properties of the printed material were evaluated, including mechanical strength (flexural and compressive strength) and qualitative microstructural characteristics. The obtained results were compared with those for conventionally cast foamed concrete specimens, and, for 3D-printed specimens, two alternative curing conditions were proposed. The findings highlight the main effects of 3DCP on hardened-state material performance and underscore key aspects – such as air-void shape stability and moisture control in air curing conditions – that require further optimization and control to enhance material performance in view of future applications of this emerging technology.

Keywords: Additive manufacturing; 3D Concrete Printing; Lightweight foamed concrete; Material properties; Mechanical strength; Microstructural characteristics.

See full Paper in the Proceedings

Use of Excavated Soil as Fine Aggregate in 3D-Printed Concrete: Effects on Fresh Properties, Strength, and Carbon Uptake

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Abstract. This study investigates the incorporation of natural soil (4% clay) as a supplementary fine aggregate in 3D concrete printing. The primary objective was to evaluate whether reducing binder content while increasing soil content could still yield printable mixes with adequate strength and enhanced carbon uptake. A blended binder comprising ordinary Portland cement (OPC), fly ash, and ground granulated blast furnace slag (GGBS) was used. Three mixes were designed: the control mix (C) with a sand-to-binder ratio of 1.6, and soil-based mixes A30 and A50 with ratios of 2.08 and 2.40, achieved by adding 30% and 50% of soil. Two curing regimes were applied: conventional water curing and accelerated carbonation curing (6 h CO_2 exposure after 24 h of printing), followed by water curing. The experimental program examined fresh properties (extrudability and buildability), compressive strength development, and carbon uptake. Soil incorporation significantly improved fresh properties, allowing higher printable heights (435–446 mm) compared to the control (260 mm). However, soil-based mixes showed early-age strength reductions of up to 85%, though the gap narrowed up to 60% at 28 days due to continued hydration of the binder and the clay fraction. The overall reduction was obvious due to lower binder content. Carbonation further influenced strength development, causing up to 78% loss at 1 day but only up to 35% at 28 days, reflecting ongoing hydration and $CaCO_3$ precipitation, which densified the system. The higher early-age losses were mainly linked to C–S–H decalcification. Despite reduced binder, soil-based mixes achieved 7–8% higher carbon uptake than the control. Overall, soil incorporation improved fresh properties and carbonation potential, while strength losses could be partially compensated through carbonation.

Keywords: 3D concrete printing, Soil, Extrudability, Compressive strength, Carbon uptake.

See full paper in the proceedings.

CONCRETE RHEOMETRY: MISSION IMPOSSIBLE?

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Abstract

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

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

Keywords: Concrete, Plug flow, Rheology, Rheometry, Viscosity, Yield stress

DEVELOPMENT OF BIO-BASED MORTARS WITH ADVANCED FUNCTIONALITIES FOR 3D-PRINTED MODULAR CONSTRUCTION

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Abstract

The BIOGEMSE Project aims to transform modern construction through bio-intelligent, sustainable, and safe modular solutions enabled by Additive Manufacturing (AM). The project focuses on the development of circular bio-based materials, optimization of AM processes, and functionalization of bio-mortars with advanced additives.

AIMEN leads the formulation of eco-efficient mortars from industrial bio-waste, starting with characterization of commercial cementitious materials in fresh state to define printability criteria such as rheology, extrudability, buildability, and early structural evolution. Building on these benchmarks, bio-based binders are engineered for tunable setting and cohesion, while mortars are developed incorporating functional bio-aggregates that enhance structural stability and reduce material costs. Specialized rheology modifiers are added to achieve AM-compatible extrusion, layer adhesion, and overall printability. Finally, advanced additives such as TiO_2, biochar, and PCMs (phase change materials) provide multifunctional properties including thermal regulation, pollutant degradation, and CO_2 capture.

Simultaneously, AM processing parameters—including pumping behavior, deposition rate, layer stability, and setting kinetics—are optimized to enable robotic 3D printing and industrial upscaling. The resulting bio-intelligent modular components will be validated in three Smart Living Labs under diverse climatic and functional conditions, demonstrating performance, scalability, and potential for wide adoption in the European construction sector.

Keywords: Bio-based materials, Sustainable construction, Additive Manufacturing, rheology.

The rheology of cement systems containing carbonated cement paste

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Abstract. Given the efficiency of reducing the carbon footprint of cement and concrete by using alternative raw materials for their production, attention should be paid to the largely unused source of raw materials obtained through the more efficient recycling of old concrete. This approach allows to produce clean recycled coarse aggregates, sand, and cement paste. In this case, recycled cement paste can be reused as a replacement for part of the cement or fine aggregates. Using carbonated recycled cement paste as a supplementary cementitious material in concrete seems to be an especially efficient solution, as carbonating the paste not only binds CO_2, but also results in some pozzolanic reactivity. At the same time, the most noticeable negative effect of carbonated cement paste reactivity is a decrease in the workability retention of cement mortars and concretes, especially when superplasticizers are used. The deterioration of the workability of such systems has been explained by the reaction of the decomposed (due to carbonation) products of calcium aluminates with the cement portlandite, resulting in the uncontrolled precipitation of ettringite and monosulfate. One possible solution to this problem is to control such precipitation reactions using retarders.

Keywords: rheology, recycled concrete, cement paste, carbonation, superplasticizer

See full paper in the proceedings.

STRUCTURAL BUILD-UP OF ALKALI-ACTIVATED SLAG PASTE: SEPARATING REVERSIBLE AND IRREVERSIBLE CONTRIBUTIONS

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Abstract

Modern concrete applications, such as 3D concrete printing (3DCP), require specific rheological features. The structural build-up, understood as the yield stress gain over time, is a complex phenomenon consisting of reversible yield stress gain (*i.e.*, thixotropy) and irreversible gain (related to reaction progress). In this work, we evaluated the structural build-up of slag paste activated with sodium silicate + sodium hydroxide through time-resolved yield stress measurement up to 90 min in both pre-sheared and resting samples, allowing us to separate the reversible and irreversible contributions. In addition, we conducted isothermal calorimetry, time-resolved synchrotron X-ray diffraction (XRD), and ^{27}Al and ^{29}Si solid-state nuclear magnetic resonance (SS-NMR) to assess the early reaction of the system. Rheological tests showed a high structuration rate (*i.e.*, A_{thix} parameter) of 65 Pa/min in resting paste samples, while pre-sheared samples had virtually no yield stress variations over the first 90 min of reaction. Calorimetry, SS-NMR, and XRD revealed a negligible slag reaction degree over the first 120 min. Thus, our results demonstrate that the structural build-up of the alkali-activated slag system basically originated from flocculation and was completely reversible, being advantageous for practical 3DCP applications.

Keywords: Slag; Alkali-activated materials; Rheology; NMR; Calorimetry.

ONE-PART ALKALI-ACTIVATED SLAG FORMULATION FOR 3D CONCRETE PRINTING APPLICATIONS

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Abstract

Alkali-activated materials (AAM) are a promising alternative to Portland cement, but the usual need for dealing with two-part systems – a precursor material and an alkaline activator (usually liquid) – may bring practical drawbacks. This becomes increasingly important in the context of "ready-to-mix" commercial formulations, ideal for on-site applications. This work assessed the performance of a commercial one-part slag-based AAM for 3D concrete printing (3DCP) applications. For this purpose, the binder mixture design was adjusted in terms of alkali content to achieve appropriate compressive strength (>42.5 MPa at 28 days and >15 MPa at 1 day). The 3DCP formulation was designed to allow a moderate initial yield stress (<1 kPa) while having enough structural build-up to allow a vertical deposition time below 1 min, compatible with on-site 3DCP applications. The 3DCP formulation was tested through rotational rheometry and fresh-state compression over time and was validated in the laboratory by the production of a meter-scale bench. Our results demonstrated that one-part slag-based AAM is a promising material for 3DCP applications, with moderate paste viscosity and high thixotropy.

Keywords: 3DCP; 3D printing; Slag; Alkali-activated; Rheology.



SUSTAINABILITY:

carbon footprint

preservation of raw materials

durability

re-use

recycling

demountable structures

LCA

Durability of polymer-based coatings on reinforced concrete bridges curbs

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Abstract. Reinforced concrete for infrastructure requires a service life up to 100 years. The infrastructures are widely exposed to atmospheric detrimental agents, such water, wind, humidity, temperature, CO_2 and chlorides. The combination of cyclic exposure, geographical orientation and human-related activities, such as salt spreading during the winter in locations 500 meters above the sea level, promotes the degradation and corrosion. Bridge curbs are subjected to salty solutions and carbonation. The polymer-based coatings are often applied to reduce chloride penetration in concrete. Nonetheless, several bridge curbs revealed a premature degradation, with cracking and layer detachment of the polymer coatings after a short time ranging from 2 to 15 years. The rapid damage was not directly related to the number of layers in the coating system. The type of polymer, such as acrylic materials, exhibited an accelerated damage and peeling off the surface layer. The coarse or inhomogeneous granulometry of the substrate, concrete or repair mortars, as well as the application technique also contributed to the variable thickness of the layers. In this case, the coating system showed a reduced durability. Not rarely, the curbs exposed to the South side were highly exposed to a cyclic temperature variation and were more damaged. On the other hand, the partial coating of the curb did not increase the deterioration speed. The mineral addition within the polymer-coated layers did not always increase the long-term resistance. Polymer-based coatings exhibited a highly variable resistance with a trend towards a life span well below 10 years. The systems were also sensitive to the application technique. This fact requires a more careful application or a frequent restoration, especially in altitude in the presence of the frost action. In this regard, the polymer-based coatings on concrete curbs rise some questions about the effective long-term protection of such reinforced concrete elements.

Keywords: reinforced concrete; bridge, polymer, coating, durability

See Full Paper in the proceedings

DURABILITY AND MECHANICAL PERFORMANCE OF 3D PRINTED CONCRETE INCORPORATION RECYCLED CONSTRUCTION AND DEMOLITION WASTE

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Abstract

This study investigates the use of recycled construction and demolition waste (CDW) as a replacement for natural fine aggregate in 3D printed concrete (3DPC), addressing both sustainability and performance. As the construction industry seeks to reduce its environmental footprint and preserve natural resources, CDW offers a promising path for material circularity and waste minimization. Natural sand was replaced with CDW at 25%, 50%, and 100%, and mechanical and durability performance were evaluated. Compressive strength tests at 28 days showed minimal effect at low replacement levels, while 100% replacement increased strength by up to 21%, ascribed to improved particle packing. Durability, assessed via oxygen permeability, water sorptivity and chloride conductivity, decreased at partial replacement but reached “excellent” performance at 100% replacement, reflecting a denser, more homogeneous microstructure. These results demonstrate the potential of CDW as a sustainable, high-performance aggregate for 3DPC and provide guidance for optimizing mix designs to support circular material use and low-carbon construction in additive manufacturing.

Keywords: 3D printed concrete, construction and demolition waste, durability, sustainable construction.

See full paper in the Proceedings

Lattice discrete particle modelling of recycled aggregate concrete: calibration and validation

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Abstract. Recycled aggregate concrete (RAC), a promising alternative for mitigating negative effects of construction and demolition waste (CDW), demonstrates significant material heterogeneity that poses challenges for its widespread structural application. Moreover, existing mesoscale modelling approaches frequently struggle to accurately represent the multiphase heterogeneity of RAC. Nevertheless, the Lattice Discrete Particle Model (LDPM) has proved to be a robust and versatile computational approach for simulating fracture in concrete, standing for its capability to capture the heterogeneity while keeping computational efficiency. Given the limited application of LDPM for simulating mechanical behaviors of RAC, this study presents a preliminary investigation towards mesoscale parameter calibration and macroscale validation. LDPM parameters are calibrated by fitting numerical results from compression and direct tension tests to experimental data, while splitting tension tests are used for validation. The results indicate that LDPM provides a great capacity for capturing the mechanical behavior of RAC, laying a solid foundation for further mesoscale modelling investigations of RAC.

Keywords: Mesoscale modelling, Lattice Discrete Particle Model (LDPM), Recycled aggregate concrete, Calibration.

See full paper in the proceedings

Potential of Using Agricultural Residues in Composite Materials

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Abstract. Agricultural residues generated from crop production and agro-processing pose a significant challenge in terms of their disposal or valorization. This study investigates the potential of utilizing these residues in the construction sector, particularly in composite materials such as concrete and mortars. By incorporating agricultural waste as aggregates, insulation additives, fibers, or partial cement replacements, the environmental footprint of traditional cement-based materials could be significantly reduced under certain conditions. This approach promotes circular economy principles by recycling organic waste, decreasing reliance on virgin resources, and mitigating greenhouse gas emissions. This research describes the types and availability of agricultural residues in Europe and America, and assesses the most promising applications in concrete and mortars based on a literature review. The findings highlight the feasibility and benefits of integrating agricultural residues into construction materials, emphasizing the need for consistent supply chains and material performance validation. This work provides a foundation for advancing on construction materials in the western world, fostering a symbiotic relationship between the agricultural and construction sectors.

Keywords: Agricultural residues, Concrete, Mortar, Circular Economy.

See full Paper in the Proceedings

DETERMINATION OF THE OXIDATION DEPTHS OF GGBFS-CONTAINING CEMENT PASTES USING MANGANESE K-EDGE XANES SPECTROSCOPY

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Abstract

The redox potential of the pore solution of hardened cements containing ground granulated blast furnace slag (GGBFS) is a crucial factor for reinforcement corrosion and immobilization of radioactive waste. However, to date no method has been established to determine the depth to which such cements have been oxidized after exposure to air. In the present study, Mn K-edge X-ray absorption near-edge structure (XANES) spectroscopy was applied to determine the depth profile of the oxidation state of manganese in hardened CEM III/B, alkali-activated slag (AAS), an alkali-activated calcined clay-GGBFS blend, and CEM I. The results show that complete oxidation occurred in the outer regions of some of the GGBFS-containing cement pastes, but the depth to which this had occurred was not identical with the 'blue-green/white colour change front' (which is usually interpreted as indicating oxidation of sulfur species). For CEM III/B, oxidation of manganese occurred in the outer regions, while the colour change of the material was gradual and thus not suitable for a determination of the oxidation depth. For the AAS, a distinct colour change front was found, but full oxidation of sulfur and manganese had not occurred in the brighter regions. Thus, Mn K-edge XANES spectroscopy is a more reliable method to follow the ingress of the oxidation front into GGBFS-containing cementitious materials.

Keywords: Manganese; X-ray absorption near-edge structure; ground granulated blast furnace slag, oxidation, colour change

ENVIRONMENTAL COMPATIBILITY OF WASTE INCINERATION ASHES AS A SUBSTITUTION FOR AGGREGATES

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Abstract

In Germany, approximately 5.7 Mt/a of incinerator bottom ash are produced through the incineration of municipal waste. This ash has a complex material composition, including metallic particles, glass fragments and minerals. A new approach to separate the components was developed in the ASHCON research project. In the first step, electrodynamic fragmentation was used to separate grains at material interfaces. In the next step, Fe and NE metals were separated, and the glass was sorted out using optical sorting. The project aimed to replace natural aggregates of the 2/8 mm grain size fraction in ready-mixed concrete and paving stones with these secondary raw materials. This should reduce the use of primary raw materials and integrate the waste ash into the material cycle, thereby diminishing the demand for landfill space. The environmental compatibility was analysed as part of the ASHCON project. For this purpose, various tests were conducted on the treated Waste Incinerator Bottom Ash (tIBA) and on concrete mixes with the tIBA as a partial substitute for aggregates. Firstly, XRF analysis and aqua regia digestion were carried out on the tIBA. The following leaching tests included a batch test at w/s-ratio of 2 (according to DIN 19529) and a pH-dependence test (according to EN 14429). The tIBA was used to produce concrete test specimens for a Dynamic Surface Leaching Test (DSLT, according to EN 16637-2). Additional concrete samples were broken after 500 days and analysed for their recyclability using a column test (following DIN 19528). A pH-dependence test was also conducted on the RC concrete to compare the mobilisation of heavy metals in the original state and the cementitious system. The data were used to carry out thermodynamic modelling with the LeachXS/Orchestra program to investigate the binding mechanisms of the trace elements contained in the treated waste incinerator residues.

Keywords: Incinerator Bottom Ash; Secondary Raw Materials; Environmental Compatibility; Thermodynamic Modelling

WASTE PLASTIC REINFORCED WITH CONSTRUCTION DEMOLITION WASTE - NOVEL WASTE STREAM

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Abstract

In the face of rapid technological and industrial development, urban environments are under increasing pressure to adopt sustainable resource management strategies. Key to this transition is the integration of circular economy principles, which emphasize material reuse, recycling, and life cycle extension. Plastics, despite their widespread use and benefits, present significant environmental challenges due to high energy demands, carbon emissions, and landfill accumulation. With global plastic production reaching 413.8 million tons in 2023 and construction demolition waste approximating 700 million tons in 2020, innovative solutions are urgently needed. This study investigates the use of construction waste as a filler in polymer composites to enhance sustainability in urban systems. Specifically, an Acrylonitrile Butadiene Styrene (ABS)-based composite was modified with up to 30% waste-derived aggregate, and its impact resistance was analyzed. The objective is to assess how recycled content affects mechanical performance, particularly fracture energy under impact loading. The research aligns with the European Waste Framework Directive and the Waste Management Hierarchy, which prioritize waste prevention, reuse, and recycling. By incorporating waste into high-value applications such as composite materials, the study contributes to both waste reduction and the development of eco-efficient construction materials. The results offer insight into balancing environmental benefits with material performance, advancing sustainable urban infrastructure and supporting the broader goals of a circular, low-carbon economy.

Keywords: Acrylonitrile Butadiene Styrene, Construction Demolition Waste, Waste Management, Circular Economy, Sustainability

INSIGHTS INTO ASR-INDUCED CRACKING: MECHANISM OF PRODCUCT FORMATION, EXPANSIVE STRESS AND CRACK PROPOGATION

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Abstract

Alkali-silica reaction (ASR) and ASR-induced cracking are complex chemo-mechanical phenomenon that occurs due to the reaction of the reactive silica in the aggregates and alkalis from the cement. This reaction produces ASR products with volume increase up to 100%, causing internal expansive stress and ultimately cracking. Despite numerous studies, the sequence of the ASR process remains unclear, due to the dynamic coupling of the transport of the ions, which affects the formation of ASR products that further exert pressures resulting in cracking and altering transport pathways.

This work elucidates mechanisms of ASR by employing a novel coupled framework combining transport, thermodynamics, and mechanical models at the pore/meso-scale. A multi-ion lattice-Boltzmann transport model is combined with a dissolution and thermodynamic model to simulate the dissolution of silica and the formation of ASR products at the aggregate and cement interface. The build-up of the ASR products results in internal expansive pressure computed using crystallization pressure theory. This is finally combined with the discrete element-based mechanical model to simulate the initiation and propagation of cracking. This study aims to provide a comprehensive understanding of the formation of ASR products at different locations, the buildup of internal expansive pressure, and the subsequent propagation of cracks.

Keywords: Alkali silica reaction, concrete cracking, thermodynamics, lattice Boltzmann method, discrete element method.

LIFE CYCLE ASSESSMENT OF REINFORCED CONCRETE STRUCTURES EXPOSED TO XC4 EXPOSURE CLASS: THE INFLUENCE OF CEMENT TYPE AND LOCAL MICROCLIMATE

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Abstract.
Carbonation is the most common corrosion mechanism of reinforced concrete structures. The aim of the study is to examine how the parameters of the concrete and the local climate of an area affect the progress of the phenomenon. For this purpose, an accelerated carbonation experiment was carried out on the mixtures under consideration. The results were used in a certified carbonation depth prediction model, based on which, the necessary number of repairs and the long-term cost of a hypothetical structure were calculated. The experimental process showed that the type of cement used, and the strength class of the concrete have an impact on the carbonation depth of the concrete. Using an analytical model, it is concluded that areas with high relative humidity and a large number of days with precipitation per year exhibit reduced carbonation depths, as well as that increasing the wet curing period of concrete markedly increases the resistance of concrete to the phenomenon. Finally, using each material's EPD value, total CO_2 emissions were calculated for each case using LCA methodology, showcasing that emissions reduction when using new types of cement is ensured only after the application of prolonged wet curing periods.

Keywords: Concrete, Cement, Carbonation, Climate, Curing, Repairs, Emissions

See Full Paper in the Proceedings

Influence of crystalline admixtures on the durability of concrete mixtures

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Abstract. Crystalline admixtures are a class of materials used to reduce the water permeability of concrete when exposed to hydraulic pressure. According to the American ACI Standard, they are classified as PRAH (permeability reducing agents under hydrostatic pressure). Their principle of operation is based on the formation of salts that block the pores when the concrete comes into contact with water under pressure. This work examines the effect of crystalline admixtures on the durability of concrete mixtures against carbonation and against chloride penetration. For this purpose, six concrete mixtures were prepared, with and without the use of crystalline admixtures. The resistance indices against chloride penetration and against carbonation were measured in these mixtures. It was observed that the addition of crystalline admixtures to the concrete mixture improved the resistance indices in each case, thus contributing to the extension of the service life of the structures. The percentage increase depended on the water-to-cement ratio of the concrete as well as the type of corrosion mechanism.

Keywords: Crystalline Admixtures, Durability, Chlorides, Carbonation, Blended Cements

See Full Paper in the Proceedings

Durability of concretes produced with low carbon cements

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Abstract.
The cement production process is a polluting activity, due to the large amounts of carbon dioxide released into the atmosphere during the production of clinker. The aim of the cement industry is to reduce the amount of pollutants released, to address the greenhouse effect. New types of cement have been introduced to the European market in recent years, with the aim of reducing the environmental footprint of cement. These new cements consist largely of pozzolanic materials, while the amount of clinkers has been reduced. Low carbon footprint cements have been fully studied regarding the development of their compressive strength, but their long-term resistance to various corrosive agents has not been sufficiently studied yet. The aim of this work is to study the behavior of concretes prepared using low carbon footprint cements against carbonation and against chloride penetration. For this purpose, six concrete mixtures were prepared with a combination of blended cements and different W/C ratios. The resistance indices against chloride penetration and against carbonation were measured. Life365 software was used to calculate the service life of structures cast with these mixtures. The service life of low carbon footprint mixtures against chloride penetration is satisfactory.

Keywords: durability, chlorides, carbonation, low carbon cements

See full Paper in the proceedings

THE CALCINATION OF DREDGED SEDIMENTS USING DIFFERENT ORDERS OF MAGNITUDE OF RESIDENCE TIME AND UNDERSTANDING ITS IMPACT ON REACTIVITY AS SCM

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Abstract

Limestone calcined clay cements are rising as low-carbon cements. The traditional formulation based on kaolinitic clays is not possible in all regions in the world, due to the limited occurrence of kaolinite. This limitation can be overcome by utilizing clay-rich mineral waste, such as dredged sediments and soil recycling sludges. Despite their kaolinite-poor composition, they have been shown to deliver desirable performance as supplementary cementitious material. The phase composition of clay-rich mineral waste, as well as the origin of its reactivity is more complex than for kaolinitic clay. Dredged sediments from the storage facilities at the port of Antwerp were studied. Calcination was carried out in a box furnace and lab-scale rotary furnace to study residence times from 1 hour to 10 seconds, while screening different temperatures. The phase compositions and microstructures were investigated to unravel the origin of the observed reactivity. The reactivity was optimized up to 350 J/g (7-day heat release in the R^3 test EN 196-12), while only values up to 270 J/g were observed after flash calcination in previous work. These results underline the complexity of dredged sediments and the need for understanding the origin of reactivity to enable an optimized use for the sediments.

Keywords: Calcined clay cement; calcined dredged sediments; reactivity screening; flash-calcination

ECOPAVE: TOWARDS SUSTAINABLE CONCRETE PAVEMENTS USING HIGH VOLUMES OF CONSTRUCTION, DEMOLITION, AND INDUSTRIAL WASTES AS CONSTITUENT REPLACEMENTS

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Abstract

Rigid pavements are increasingly preferred in developing countries such as India because of their durability and long service life. However, the extensive use of natural materials in concrete makes this choice both unsustainable and economically challenging. The ECOPAVE project tackles this problem through a collaboration involving Indian and German academic and industrial partners funded by Indo-German Science & Technology Centre (IGSTC). The project investigates the simultaneous replacement of Portland cement and natural aggregates with large proportions of locally sourced waste materials, challenging current norms to deliver economically viable and sustainable solutions. The initiative aims to build a comprehensive scientific understanding of the microstructure and properties of concrete that incorporates waste materials at high replacement levels. Here, more than 50 % in pavement-quality surface concrete and up to 90 % in sub-grade concrete should be replaced to demonstrate its practical application. This contribution will present the key achievements of the project so far. This includes processing strategies for waste materials, microstructural evolution and strength development of composite binders, tested the mechanical performance of concrete made with recycled aggregates and composite cements, and a machine-learning framework to optimise mix design. In addition, data-management strategies implemented to facilitate this international collaboration will also be discussed.

Keywords: Rigid pavements, Waste material, Recycled concrete, International collaboration

Effect of selective demolition and recycling method on properties of recycled concrete aggregates

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Abstract. Recycled concrete aggregates are rarely used in infrastructure projects for high-grade applications. Specifically, in the Netherlands the natural coarse aggregates may be partially replaced by recycled concrete aggregates (RCA) up to a maximum replacement percentage of 30% (by volume) in high strength concrete ≥C40/50 and in environmental classes XD, XF and XS. The Dutch Ministry of Infrastructure, Rijkswaterstaat (RWS), initiated a framework "Proeftuin Recyclaat" where pilot studies are conducted to understand the impact of parent concrete quality and use of advanced recycling techniques on quality of RCA generated in RWS demolition projects. These combined efforts are expected to increase the allowable replacement percentages of natural aggregates with RCA, not only for coarse aggregates but also to support the use of high-quality fine RCA. In this context, "high-quality" means that RCA can be used in future high-performance structural concrete with a required lifespan of 100 years.
In the present study, RCA resulting from selective demolition of known quality of parent concrete was characterized. The test materials were selectively produced from demolished T-prestressed girders, columns, abutments, and foundations, all from one viaduct. The concrete rubble was recycled using two advanced recycling techniques Smart Liberator and Mangeler (0-0.125 mm, 0.125-4 mm, 4-22 mm), as well as a traditional rotor/impact technique (0-4 mm, 4-22 mm). Aggregate quality is measured in terms of product physical and chemical properties. Special attention was paid to the properties of RCA such as chemical composition, increased aggregate recovery, water absorption, and the Los Angeles coefficient. A systematic valorization of all particle size fractions was suggested based on the quality of the RCA used. The high potential to develop high-quality structural concrete using RCA as a total replacement for natural aggregates was outlined.

Keywords: Selective demolition, Structural concrete, Advanced recycling, Recycled aggregates, Quality control

See Full Paper in the Proceedings

COMPARATIVE ANAYSIS ON DIFFERENT TEST METHODS TO EVALUATE SELF-HEALING PERFORMANCE OF MORTAR USING MINERAL ADMIXTURE

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Abstract

In recent years, self-healing concrete has gained much attention from scientific community and construction industries. Using physical, Chemical and biological methods, various advanced technologies have been incorporated into them. As the self-healing material technology developed, many researchers have suggested various test methods to evaluate self-healing performance as well. However, a reliable experimental method has not been reported, making it difficult to reproduce the results. In this study, mortar specimen with 0.3 mm crack width has been made using mineral self-healing admixture and its self-healing performance has been evaluated via three different test methods with identical specimen: constant water head permeability test, Chloride diffusion test, Gas diffusion test. Results showed that mineral admixture made increase in healing rate compared to plain mortar after 28 days of healing period in every test method. Furthermore, by analysing the relationship between crack width and output from each test methods, coefficient was specified for each test and utilized to estimate diminishing crack width. It has been found that different test methods had approximately equal estimated crack width.

Keywords: Self-healing concrete, Mineral self-healing admixture, Water permeability, Chloride penetration, Gas diffusion, Crack width control

EMBODIED ENERGY AND CARBON FOOTPRINT OF SUSTAINABLE ASPHALT DIKE INNOVATIONS: A COMPARATIVE STUDY

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Abstract

The Netherlands relies heavily on dike revetments to protect its low-lying regions from flooding and rising sea levels. As many of these flood defences are approaching the end of their service life, there is a strong thrust to adopt sustainable and circular construction practices. Several innovative asphalt-based revetments incorporating recycled and bio-based materials have been implemented to this end. Although research is emerging to characterise their durability, the environmental performance of such designs remains unexplored. This cradle-to-gate life cycle assessment (LCA) study therefore evaluates the embodied energy and carbon footprint of two asphalt dike innovations : (i) a polymer-modified asphalt mix containing a bio-based filler, and (ii) a mix containing 50% reclaimed asphalt (RA), comparing the results with those of a conventional hydraulic asphalt mix. All three revetments were designed to meet fatigue failure criteria and have been implemented in the field. The unit of measurement was the surface layer (asphalt) of a dike segment measuring 1500 × 10 × 0.25 m, and the data were collected through stakeholder interviews and surveys covering material inputs, productivity, and equipment fuel use. The results indicated that the RA-based mix reduced embodied energy and carbon emissions by approximately 26% and 14%, respectively, compared to the conventional mix, primarily due to the lower demand for virgin materials. Conversely, the polymer-modified mix had the greatest environmental impact due to its energy-intensive production process. Preliminary findings suggest that incorporating a high RA content in hydraulic asphalt layers can significantly reduce environmental impact. However, future attempts must ensure that such innovations perform satisfactorily throughout their service life, without requiring significant maintenance and thus offsetting the initial benefits. Overall, the results provide stakeholders and infrastructure planners with valuable insights into aligning dike construction with sustainability goals.

Keywords: lifecycle assessment, embodied energy, carbon footprint, hydraulic asphalt, reclaimed asphalt materials, dike revetments

Effect of Calcium Hydroxide on the Properties of Lithium Slag-slag-red Mud Based Composite Cement

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Abstract. Portland cement (PC) is the world's most widely used cementitious materials. However, its production process emits substantial amounts of CO_2. Reducing carbon emissions from cement is crucial for the sustainable development of the cement industry. Rapid industrial growth has generated vast quantities of industrial solid wastes (ISWs), such as lithium slag and red mud. Utilizing these ISWs to partially replace PC in composite cement represents an effective pathway for the low-carbon transition of the cement industry. Nevertheless, substituting PC with low-activity materials like lithium slag and red mud significantly compromises cement performance. Therefore, this study employed calcium hydroxide to optimize the properties of a composite cement based on lithium slag, slag, and red mud, investigating its influence. The results indicate that calcium hydroxide reduced the fluidity of the composite cement and prolonged its setting time. At early hydration ages (3 d), increasing calcium hydroxide content decreased the compressive strength of the composite cement mortar. After 7 d of hydration, however, the compressive strength gradually increased with higher calcium hydroxide content. By 56 d of hydration, the compressive strength of composite cement mortars with 8% to 12% calcium hydroxide exceeded that of OPC paste. Compared to PC, the composite cement paste exhibited a significant increase in shear stress and correspondingly higher viscosity. The effect of calcium hydroxide on rheology was not distinctly clear, though it generally reduced the paste's shear stress. Calcium hydroxide provided additional alkalinity during the hydration of the composite cement, promoting the pozzolanic reactions of lithium slag and red mud. Furthermore, the alkaline components present in the red mud also contributed to the alkaline environment for composite cement hydration. This research not only provides a feasible technology for the low-carbon and sustainable transformation of traditional cement but also offers effective pathways for the resource utilization of ISWs.

Keywords: Composite cement, Industrial solid wastes, Resource utilization, Calcium hydroxide, Properties.

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Influence of bioaggregates type on the performance of sprayed lightened earth walls

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Abstract. In the context of environmental transition, geo- and bio-sourced materials offer promising solutions for the building sector. Light earth provides sustainable benefits such as CO_2 storage and the valorization of agricultural by-products, while improving indoor hygrothermal regulation. To move beyond artisanal practices, spray application for wall filling emerges as a viable industrial-scale technique. Yet, its performance remains poorly documented.
This study investigates the feasibility of mechanized spraying of light earth using five plant aggregates: two types of hemp shiv, two types of crushed miscanthus stalk, and sunflower bark. Spraying was performed with an industrial machine applying clay slurry onto wooden frames and cubic molds.
Results show that hemp shiv and sunflower bark are the most suitable aggregates, ensuring good cohesion, adhesion to the substrate, and regular application. By contrast, miscanthus stalk particles exhibit limitations related to their morphology, including slipperiness and mechanical blocking. Overall, this work demonstrates the technical feasibility of mechanized spraying of light earth enriched with bio-aggregates, while highlighting the importance of aggregate processing quality and material design for successful implementation.

Keywords: Light earth – Bioaggregates – Spray manufacturing – Mechanical strength – aggregate processing.

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COMPARATIVE ANALYSIS OF NUMERICAL MODELS FOR CORROSION-INDUCED CONCRETE CRACKING

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Abstract

The durability of reinforced concrete is significantly affected by corrosion-induced concrete cracking during the corrosion propagation phase. However, life assessments often rely on depassivation of the steel reinforcement as a key threshold, which is insufficient to predict long-term performance because depassivation does not necessarily lead to active corrosion or concrete cracking. Therefore, a more accurate representation of the damage evolution process is critical for accurate lifetime prediction.

To improve the prediction of long-term performance, numerical models are increasingly used to simulate the mechanical damage caused by rebar corrosion. These models range from simplified approaches to complex multi-physics formulations. For practical application in engineering design and assessment, models must balance physical accuracy with computational efficiency.

This study presents a comparative analysis of established numerical models for rebar corrosion-induced concrete cracking. The models can be broadly divided into two groups: simplified approaches that idealize the reinforcement as a one-dimensional element to maximize computational efficiency, and detailed models that explicitly represent the steel, corrosion products, and surrounding concrete as solid bodies.

Representative benchmark cases are employed to evaluate the predictive capabilities of each model under controlled and comparable conditions. Particular emphasis is placed on evaluating how accurately each model simulates the complex interaction mechanisms between steel reinforcement and surrounding concrete.

Keywords: Corrosion, Numerical Modeling, Service-Life Assessment, Concrete Cracking, Durability

DURABILITY OF ALKALI-ACTIVATED SLAG MORTARS UNDER SODIUM AND MAGNESIUM SULFATE EXPOSURE

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Abstract. This study investigates the durability of alkali-activated slag (AAS) mortars in sulfate-rich environments, with a focus on long-term expansion behavior under sodium sulfate (Na_2SO_4) and magnesium sulfate ($MgSO_4$) exposure. Two AAS mixes were prepared using ground granulated blast furnace slag (GGBFS) activated with alkaline solutions of identical Na_2O content (n = 4.0 g/100 g GGBFS), but differing silicate moduli (Ms): 0.5 (AAS0.5) and 1.9 (AAS1.9). The performance of these mixes was compared to that of an ordinary Portland cement (OPC) mortar. Prismatic specimens (40 × 20 × 160 mm³) were submerged in sulfate solutions for over four months, and the expansion was periodically measured to assess sulfate-induced deterioration.

During the initial stages of exposure, both AAS mixes exhibited slightly higher expansion than OPC. However, after approximately 100 days, OPC mortars experienced a marked and progressive increase in expansion, particularly in Na_2SO_4 solution. In contrast, AAS specimens remained dimensionally stable throughout the testing period. The long-term expansion behavior of AAS0.5 and AAS1.9 was comparable, indicating that variation in silicate modulus had minimal impact on the sulfate resistance under the conditions studied. Additionally, AAS mortars displayed similar performance in both Na_2SO_4 and $MgSO_4$ environments, whereas OPC showed significantly greater expansion in Na_2SO_4, demonstrating higher sensitivity to the sulfate type.

This investigation complements previous studies on the same AAS mixes focused on microstructure development, alkali-silica reaction (ASR), and creep, contributing to a comprehensive understanding of their long-term performance.

Keywords: Alkali-activated slag, sulfate, Na_2SO_4, $MgSO_4$

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Assessing the Sustainability Performance of Built Heritage Structures through Indicators: Integrating Life Cycle Thinking and Regulatory Frameworks

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Abstract. As the significance of sustainability in built heritage becomes more widely acknowledged, sustainable building performance and life cycle assessment are receiving more attention. In recent years, the academic community has been increasingly interested in sustainability, with the aim of achieving zero CO_2 emissions. Furthermore, the sustainability indicators play a key role in minimizing the environmental impact of the construction sector associated with the Life Cycle Assessment (LCA). This study aims to identify and evaluate key sustainability indicators and parameters, with emphasis on long-term environmental performance and life cycle outcomes in the context of built heritage. The scope of this research is to determine the structure of sustainability indicators through classification of three pillars of sustainability with assessment criteria and standards such as UN Sustainable Development Goals (SDGs) and Level(s). The study sheds light on sustainability indicator selection in the field of heritage protection, such as durability, energy efficiency, life cycle carbon emissions, and resource recycling. Key challenges in this subject are the lack of widely universal sustainability indicators adapted to the specific qualities of built heritage, since the variety of sustainability indicators may be different for each structure. By developing a comprehensive approach to evaluating sustainability indicators in the built heritage, the study contributes not only to drawing attention to the preservation of built heritage but also to promoting strategies that contribute to a more sustainable future. The findings will help examine policies and determine strategies that ensure the longevity and durability of built heritage while minimizing environmental impacts.

Keywords: Built Heritage, Sustainability Indicators, Life Cycle Assessment (LCA), Sustainability Principles, Environmental Impact Assessment.

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Evaluating Enforced Carbonation of Field-Sourced Recycled Concrete Fine

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Abstract. Cement production is a significant environmental concern, accounting for approximately 8% of global anthropogenic CO_2 emissions due to its high demand for raw materials and energy. Recently, the reuse of concrete has gained attention. Recycled concrete can be processed into Recycled Concrete Fines (RCF), the latter being valuable as a carbon sink due to the presence of carbonatable phases such as calcium hydroxide ($Ca(OH)_2$) and calcium oxide (CaO). Through enforced carbonation, RCF can serve as a carbon sink and possesses properties that can be classified as Supplementary Cementitious Materials (SCMs). This study aims to understand the kinematics of enforced carbonation of RCF directly collected from demolition sites. The collected RCF was carbonated under semi-dry conditions using a custom-designed rotating carbonation chamber that enables simultaneous carbonation and mechanical agitation. The carbonation of RCF was induced at various temperatures, and the transformation of RCF was evaluated through microstructural and mechanical tests. The results indicated that lower process temperatures led to the formation of vaterite due to insufficient time for transformation. Therefore, higher temperatures were necessary to increase carbonation efficiency and obtain stable calcite within the given reaction time. The presence of this stable calcite phase resulted in a marked increase in compressive strength, with the optimum results achieved in samples carbonated at 75°C. However, these results are still insufficient to conclusively determine whether this difference is solely due to carbonation temperature or to the heterogeneity of field-sourced RCF. There is a need to develop optimized processing solutions to obtain a sufficiently reactive resource.

Keywords: Recycled Concrete Fine, Enforced Carbonation, Reactivity.

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DURABILITY ASSESSMENT OF CEMENTITIOUS MATERIALS: A PORE-SCALE NUMERICAL STUDY FOCUSED ON CARBONATION

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Abstract

Cementitious materials, as a typical type of porous materials, have their durability highly related to their pore structure features. This study presents a comprehensive modelling framework for generating microstructures, characterizing pore structure features, and evaluating the durability of cementitious materials under diverse environmental conditions. Through a three-step optimization process—pore redistribution, porous growth modelling, and spatial mapping of hydration products—the lattice-based 3D representative volume element developed in this study offers a more accurate representation of the real microstructure of hardened cement paste. This generated microstructure enables quantitative determination of key pore structure features, including pore size distribution, connectivity, tortuosity, and water distribution. Furthermore, durability issues related to transport and reaction processes—such as carbonation and the coupled effects of carbonation and chloride ingress—are investigated by integrating the influence of microscopic pore structures. Compared to previous studies, the proposed framework demonstrates improved accuracy in assessing the durability performance of cementitious materials, including resistance to ion erosion and carbonation. By incorporating microscopic physicochemical mechanisms and accounting for both intrinsic and extrinsic factors—such as relative humidity, temperature, and the use of supplementary cementitious materials—this study provides new insights into the mechanisms governing long-term durability degradation in cementitious systems. This study is expected to provide a reference for the development of novel materials and the optimization of durability performance, while supporting durability-based structural design in complex service environments.

Keywords: Cementitious materials, Carbonation, Pore structure features, Lattice model

Mechanical and Microstructural Performance of Alkali-Activated Binders Based on Calcined Clays

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Abstract. Alkali-activated binders are considered a promising and more environmentally favorable alternative to Portland cement; however, their large-scale application still requires validation in terms of long-term durability, standardization, and industrial feasibility. This study investigates the mechanical and microstructural behavior of mortars formulated with three calcined clays of distinct geological origin: two clays from Mexico and one from Ecuador. The precursors were characterized with emphasis on SiO_2/Al_2O_3 molar ratios and CaO content, as indicators of gel formation type (N-A-S-H vs. hybrid N-A-S-H/C-A-S-H). Alkali activation was performed using a sodium silicate–sodium hydroxide system, optimized for SiO_2/Na_2O and solid-to-liquid ratios to balance workability and compressive strength. The Ecuadorian clay-based binder exhibited the highest compressive strength at 28 days (67.9 MPa), attributed to its favorable Si/Al ratio (3.27) and low CaO content, classifying it as a true geopolymer. In contrast, one of the mexican clays showed balanced performance that likely formed a hybrid gel due to moderate calcium content, while the other mexican clay displayed limited reactivity, with a high Si/Al ratio (4.90) and low Al_2O_3, resulting in underdeveloped gel structure and poor strength. Complementary SEM–EDS analysis supported the correlation between precursor chemistry, gel formation, and mechanical response. While the term "geopolymer" is often used generically, this study emphasizes the need to distinguish between true geopolymeric systems and broader alkali-activated materials, depending on precursor composition. These findings highlight the potential of selected low-calcium clays for developing high-performance, low-carbon binders cured at ambient temperature.

Keywords: Geopolymer, calcined clays, alkali-activated material, binders.

See Full Paper in the Proceedings

Quantifying the sustainability performance of nature-based coastal infrastructure

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Abstract. As climate change intensifies coastal hazards, hybrid nature-based infrastructure, such as dune dike systems, offers a promising pathway to enhance resilience while supporting ecological and social value. However, assessing the sustainability of these blue-grey solutions integrating engineered structures with dynamic, vegetated systems remains challenging due to the lack of tailored, quantifiable evaluation frameworks.

This research focuses on operationalizing a rating system for blue-grey coastal infrastructure developed under the DuneFront project by translating qualitative sustainability criteria into measurable impact categories. The framework is demonstrated through its application to the Katwijk coastal protection project in the Netherlands, a hybrid dune-dike system, providing a practical case to test and validate the methodology.

This work details the method for aligning project indicators, such as material sourcing, biodiversity integration, and design adaptability, with standardized impact metrics from life cycle assessment (LCA) and ecosystem evaluation protocols. The proposed approach enables a cross-scalar evaluation from cement material choice to ecosystem function, bridging laboratory innovation and real-world infrastructure implementation. It supports a comparative assessment of nature-based solutions across different sites and scenarios, aligning with emerging policy tools for sustainable activity.

Integrating material innovation with system-level evaluation offers a reproducible framework for assessing and comparing nature-based coastal solutions, advancing performance-driven design and policy alignment in the field of regenerative infrastructure.

Keywords: LCA, nature-based solutions, coastal infrastructure, bioreceptive cement, dune dike systems.

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INVERSE ESTIMATION OF CHLORIDE DIFFUSION COEFFICIENT IN HEALED CRACK USING COMSOL TECHNOLOGY

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Abstract

Chloride attack poses a serious threat to concrete structures, creating an urgent need for analytical tools to assess corrosion risk. Accurate quantification of chloride diffusion coefficients in cracks is essential for life prediction and durability design. Traditional laboratory methods struggle to estimate diffusion coefficients in healed cracks due to complex crack geometries and variability in the healing process. In this study, a multiphase transport model including crack phase, damage zone phase and undamaged zone phase was constructed based on COMSOL to systematically simulate the diffusion behaviour of chlorides in different regions. Fully healed-crack diffusion coefficient is estimated efficiently via model inversion using an optimization algorithm. The inversion development is also based designed time-varying coefficients governed by crack self-healing kinetic law. Model calibration against experimentally measured chloride concentration profiles confirms the reliability of the inversion approach, while a sensitivity analysis elucidates the dominant role of healing degree on transport rates. In additional, this research framework is applied to the study of concrete samples with different admixtures, which is used to validate the applicability and stability of the proposed method for the inversion of diffusion coefficients in healed cracks. This study provides a quantitative tool for concrete durability assessment and offers guidance for extending structural service life.

Keywords: Self-healing, Inverse problem, Chloride diffusion, Fick 2nd law, COMSOL

Performance of *Opuntia Ficus Indica* Mucilage as Corrosion Inhibitor in Cement-based Materials

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Abstract. Reinforcement corrosion in concrete structures is a world-wide problem and one of the main causes of loss of performance of concrete structures. One of the alternatives to face this problem is the use of corrosion inhibitors. Considering the actual seek for more eco-friendly materials, the use of bio-inhibitors has gained more strength in last years. The *Opuntia Ficus Indica* (*OFI*) mucilage arises in this scenario as one of these alternatives. In this work, reinforced mortar specimens with high early strength Portland cement and water to binder ratio of 0.5 were cast with different contents of *OFI* mucilage (4%, 6%, 8% and 10%). After that, they were cured in a humid chamber for 28 days and then were characterised on compressive strength and surface electrical resistivity. Another set of specimens was subjected to wetting and drying cycles in 1 Molar sodium chloride solution initially until reinforcement depassivation. Along this period, these reinforced mortar specimens were electrochemically monitored. Results show that although there is a delay in cement hydration and a slight decrease in compressive strength at earlier ages, it is not a worrying effect for the mucilage contents adopted in this work. Regarding the electrochemical performance, there is a better performance of mortar specimens with *OFI* mucilage, not only bringing the electrochemical parameters to better levels, but also extending the initiation corrosion period and not presenting reinforcement depassivation after two years of laboratory tests in chloride contaminated solution.

Keywords: Bio-inhibitor, chlorides, concrete, corrosion, Opuntia Ficus Indica.

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On a quest for curability: unveiling the paradox of sustainable concrete and its 'skin-crete' vulnerability

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Abstract. The global construction sector increasingly champions sustainability, driving the adoption of alternative binders like blast furnace slag cement (CEM III) to mitigate the significant CO2 emissions associated with traditional Portland cement (CEM I) production. While CEM I is known for robust carbonation resistance, its substantial environmental footprint prompts this vital shift. However, a critical, often overlooked factor, i.e. the initial curing execution, profoundly impacts the long-term performance of these sustainable concretes. Inadequate curing, particularly during early age, severely compromises the quality of the concrete cover (skin-crete). This deficiency is even more pronounced in CEM III concrete compared to CEM I. This creates a detrimental paradox: the presumed environmental gains from selecting CEM III are drastically undermined if proper 'curability' is neglected. A concrete structure intended for a 50-year service life might prematurely degrade, leading to costly and unforeseen maintenance, repairs leading towards a higher overall environmental impact and cost, seen from a life cycle perspective. This paper highlights this critical issue through a case study of a concrete water retaining structure cast in 2010 using CEM III. Despite its relatively young age of 15 years, it shows advanced carbonation, primarily attributed to insufficient initial curing and unprotected casting in harsh winter conditions. Intensive non-destructive testing (electrical resistivity, air permeability, rebar scanning) and destructive testing (core drilling for petrographic analysis and carbonation depth determination via phenolphthalein) was performed. Furthermore, the paper will present results from Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) studies to quantify the environmental impact and economic consequences of inadequate curing. The findings highlight that the pursuit of truly sustainable concrete solutions demands an unwavering commitment to 'curability', recognizing it as an indispensable pillar underpinning both concrete durability and its genuine environmental integrity throughout its intended service life.

Keywords: Curing, Sustainability, SCMs, Carbonation, LCA, LCCA

See Full Paper in the Proceedings.

Synergistic Utilization Of Marble Dust And Calcined Clay In Ternary Cement: A Study On Industrial By-Product Integration

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Abstract. The strategic integration of industrial waste materials in cementitious materials offers a viable pathway for reducing carbon emissions in the construction industry, while alleviating the environmental burden posed by the direct disposal of industrial residues. Among such by-products, marble dust – generated during cutting of natural marble stone – accounts for nearly 30% of quarried material, often ending up as landfill waste. The present study investigates the feasibility and performance implications of employing marble dust in conjunction with calcined clay as supplementary cementitious materials (SCMs) within ternary blended binder systems, such as limestone calcined clay cement (LC^3). In this context, a binder formulation was developed with reduced clinker content of 50%, replacing the remaining portion with a 1:2 ratio (by weight) of marble dust to calcined clay. The mechanical performance of the binder systems was assessed in conjunction with thermogravimetric analysis (TGA) after 2, 4, and 15 days of curing. Optimization of particle size distribution through refinement of the mixing procedure is also proposed. The results demonstrate that marble dust can significantly enhance the mechanical response of the ternary binder, as soon as its tendency to flocculate is mitigated by targeted strategies. In conclusion, the findings suggest that the developed ternary binder system in this study offers a technically viable and sustainable alternative to conventional Portland cement, while supporting broader goals of carbon footprint reduction and industrial waste valorization within the built environment.

Keywords: Ternary blended cement; marble dust; calcined clay; clinker reduction; sustainable construction; industrial waste reuse.

See Full Paper in the Proceedings.

Role of Alko-Amine Inhibitor Corrosion Inhibitor Formulation in Enhancing Durability of Reinforced Concrete Subjected to Chloride-rich Exposure

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Abstract. Corrosion of steel reinforcement in concrete, particularly under chloride exposure, continues to pose a serious durability challenge in the construction industry. Among various corrosion mitigation techniques, the use of chemical corrosion inhibitors (CCIs), particularly the alko-amine-based, is emerging as an effective, user-friendly alternative due to their ease of application and formulation flexibility. This study explores the role of the molecular structure of alko-amine in influencing corrosion inhibition performance, with a focus on film formation capability and durability when used as an admixture in reinforced mortar systems. Four alko-amine formulations, monoethanolamine (MEA), methyl ethanolamine (MeEA), dimethyl ethanolamine (DMeEA), and ethyl monoethanolamine (EMEA), were initially screened using industrial-level vapour-phase inhibition testing (JIS Z 1535), laboratory-level electrochemical assessment, and surface analytical technique (atomic force microscopy (AFM)). Among the tested CCIs, MEA and MeEA demonstrated superior film-forming ability, producing dense and uniform layers, while DMeEA and EMEA exhibited a weaker performance. The top-performing alko-amine CCI, MeEA, was then compared against an inorganic calcium nitrite (CN) inhibitor and a commercially available organic inhibitor (containing DMeEA) using reinforced mortar testing. The comparative study assessed the corrosion resistance ability of admixed CCI by monitoring rebar performance under chloride-contaminated conditions. MeEA added sample showed a higher inhibition efficiency (IE) and superior film characteristics of reinforcement at prolonged exposure age, compared to both commercial and inorganic counterparts. This integrated investigation underscores the importance of molecular formulation in the development of efficient CCIs. By combining formulation-level insights with practical mortar-based validation, the study presents a targeted approach for understanding CCI effectiveness to enhance the service life of RC exposed to chloride environments.

Keywords: Chemical corrosion inhibitors, Alko-amine, Film formation, Electrochemical Characteristics, Reinforced mortar, Chloride exposure.

See Full Paper in the Proceedings.

Self-compacting lightweight concrete reinforced with polypropylene fibres: Highlighting mechanical behavior and life cycle assessment

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Abstract. Addressing the twin goals of structural efficiency and environmental sustainability in construction calls for the development of multifunctional concretes. This study evaluates self-compacting lightweight fibre-reinforced concretes (SCLFRC) incorporating two expanded-perlite fine aggregates and polypropylene fibres. Four optimized mixtures were selected on the basis of fresh-state properties and compressive strength, following European standard procedures. Fresh densities were ≤ 2000 kg/m³. Mechanical testing showed that fibre-reinforced concretes had higher tensile capacity and stiffness than their non-reinforced counterparts. The fibre-reinforced mixture with perlite type B reached the highest indirect tensile strength (3.24 MPa) and elastic modulus (31.64 GPa).

To complement the mechanical programme, a cradle-to-gate Life Cycle Assessment was performed in accordance with EN 15804 and ISO 14040/44 to quantify environmental impacts. The Global Warming Potential was 269.97, 287.56, 289.19, and 297.46 $kgCO_2e/m^3$ for the control mixture with perlite type A, the control mixture with perlite type B, the fibre-reinforced mixture with perlite type A, and the fibre-reinforced mixture with perlite type B, respectively. The binder was the main contributor to impacts in stages A1–A3, while transport and plant energy were secondary contributors. When impacts are interpreted in terms of "performance per impact," the fibre-reinforced mixture based on perlite type A preserves the strength efficiency of its corresponding control mixture, and the fibre-reinforced mixture based on perlite type B improves upon its control counterpart. Therefore, the selection of perlite type and fibre dosage can be adjusted to suit the governing design criterion (stiffness/crack control versus compressive strength) with a bounded increase in GWP. This integrated assessment supports the use of SCLFRC as a sustainable material for structural applications. Its lightweight character, mechanical reliability, and improved environmental profile make it suitable for slabs, bridge decks, and precast elements where weight reduction and durability are critical.

Keywords: lightweight aggregate; expanded perlite; polypropylene macrofibres; life cycle assessment; eco-efficiency

See Full Paper in the Proceedings.

Recycling of wind turbine concrete and composite components: development of glass fibre reinforced recycled aggregate concrete

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Abstract. The use of recycled materials in concrete production is gaining increasing attention to reduce dependence on natural resources and address the growing volume of industrial and construction waste. This research focuses on the design and technical characterisation of structural concrete incorporating two types of waste materials derived from decommissioned wind turbines: coarse recycled aggregates (RA) sourced from dismantled foundations, and recycled glass fibres obtained from shredded blades. In this context, the individual and combined effects of these recycled components on the mechanical performance of concrete were investigated. Concrete mixes of recycled aggregate replacement (100%) and glass fibre dosages (0% and 3%) were designed and characterised. Particular attention was given to the assessment of compressive strength, indirect tensile strength, modulus of elasticity and residual flexural tensile strengths were analysed. The results indicate that both recycled aggregates and glass fibres can be successfully integrated into structural concrete without compromising the mechanical performance of the resulting concretes. Moreover, certain combinations proved improvements in pre- and residual flexural tensile strength, suggesting a promising interaction between the two recycled components. The outcomes of this study are expected to support the development of technically sound guidelines for the incorporation of wind turbine-derived waste in structural concrete. Furthermore, the findings contribute to a broader understanding of how recycled materials can be effectively integrated into construction practices without compromising both mechanical and durability performances, while maintaining the required structural reliability levels.

Keywords: Recycled aggregates, glass fibres, structural concrete, wind turbine waste, mechanical performance.

See Full Paper in the Proceedings.

BRIDGING THE GAP: HYBRID BINDERS AS A TRANSITIONAL SOLUTION IN CEMENT STANDARDIZATION

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Abstract

The concrete industry must urgently decarbonize to meet climate targets. Partial replacement of Portland cement (PC) with supplementary cementitious materials (SCMs), coupled with the use of recycled aggregates (RA), offers a viable path toward eco-efficient concrete. However, prescriptive standards and slow adoption of low-carbon technologies—especially alkali-activated materials (AAMs)—lead to limited progress. Hybrid binders (HB), which combine PC with high volumes of SCMs and small amounts of activators, offer a promising intermediate solution requiring minimal changes to current standards.

This study reviews the performance and reaction mechanisms of CEM III/B-based hybrid binders activated with small dosages of sodium sulfate (Na_2SO_4). The addition of Na_2SO_4 (>1%) did not alter setting time but significantly enhanced early-age strength development through improved hydration kinetics and pore refinement. Na_2SO_4 promotes both PC hydration (>80% reaction within 7 days) and GGBFS dissolution, resulting in increased C-A-S-H formation, ettringite precipitation, CH consumption, and a shift to lower Ca/Si ratios in the C-S-H gel, as confirmed by NMR and SEM-BSE analyses.

The feasibility of incorporating up to 50% low-quality coarse RA (~13% water absorption) was also discussed. While high RA content slightly compromised durability due to increased permeability, using 20% RA maintained mechanical performance and durability, aligning with circular economy goals in regions like Flanders.

Finally, the long-term potential of HBs including a high content of other SCMs is discussed. Ternary and quaternary blends (e.g., 30% PC, 10–20% GGBFS, and 50% pozzolans) show comparable performance to CEM III/B, although carbonation resistance is reduced. These results support the broader implementation of hybrid systems as a pragmatic step toward sustainable concrete.

Keywords: Hybrid binders, High volume SCMs, Low clinker contents, Recycled aggregates, Sodium sulfate.

A SUSTAINABLE HOUSING MODEL FOR FLOOD RESILIENCE AND ENERGY INDEPENDENCE IN PAKISTAN

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Abstract

Pakistan is increasingly vulnerable to the intensifying impacts of climate change, with the 2022 monsoon floods serving as a stark example. Affecting over 33 million people and inundating nearly one-third of the country, the disaster exposed critical gaps in housing resilience, particularly in rural regions like Khairpur Nathan Shah and urban centers such as Karachi. In response, this study proposes a climate-adaptive housing prototype that combines flood resilience with NET Zero performance to offer a sustainable, affordable, and context-specific solution for vulnerable communities. The prototype is designed using a buoyant foundation system composed of recycled plastic barrels and anchored timber posts, enabling the structure to remain stable under normal conditions and rise with floodwaters during extreme events. The superstructure employs bamboo and mud-lime plaster to achieve a lightweight, low-carbon envelope that aligns with both climatic needs and local construction traditions. A stand-alone solar photovoltaic system, optimized for Khairpur's solar profile of 13.1 average sun hours per day, ensures energy independence, while integrated rainwater harvesting and greywater recycling systems support water sustainability. The design methodology incorporates detailed GIS-based flood risk mapping, passive cooling strategies, stakeholder consultations, and performance-based material analysis to ensure climate responsiveness, cultural compatibility, and long-term viability. This approach contrasts sharply with expensive amphibious housing models developed in high-income countries such as the Netherlands, instead demonstrating how resource efficient materials and localized construction techniques can address systemic housing vulnerabilities in low-resource settings. The proposed model supports Pakistan's broader climate adaptation agenda and contributes to its nationally determined commitments under the Paris Agreement. Beyond Khairpur Nathan Shah, the design is scalable for informal flood-prone settlements across Pakistan, offering a replicable and resilient framework for future infrastructure. This research advances the integration of environmental performance, structural adaptability, and social equity in architectural response to climate-induced disasters.

Keywords: Climate Change Adaptation; Flood-Resilient Housing; NET Zero Design; Buoyant Foundation System; Sustainable Architecture.

Designing Biocompatible Mortar for Ericaria Amentacea Habitat Restoration: Enhancing the Ecological Value of Coastal Structures

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Abstract. *Ericaria amentacea*, a habitat-forming macroalga of high ecological importance in the Mediterranean, has been the focus of restoration project involving the deployment of 3D-printed concrete units along the Ligurian coast of Italy. Previous studies demonstrated that these prototypes supported effective colonization under laboratory and field conditions, but revealed insufficient strength to withstand marine loading, which restricted their long-term applicability. To address this limitation, the present study evaluates conventionally cast mortars in which crushed seashells were introduced as a partial replacement for natural fine aggregates. The use of shells, an abundant by-product of fisheries, is aligned with sustainability objectives and circular economy strategies. Mechanical and durability tests showed that shell-based mortars preserved flexural strength while exhibiting lower air permeability and capillary absorption, properties associated with improved performance in marine environments. The results confirm the feasibility of seashell aggregates in restoration substrates, providing a durable and scalable alternative for *E. amentacea* habitats recovery in the Mediterranean.

Keywords: *Ericaria Amentacea*, Ecological Restoration, Sustainable Mortar, Marine Aggregates.

See Full Paper in the Proceedings.

BIO-BASED EMULSION FOR PAVEMENT

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Abstract. Waste cooking oil (WCO) is used in the Post Oil Pavement (POP) project as an alternative to bitumen in road construction to reduce environmental impact. Furthermore, a part of the project focus on cold mixes to minimize the energy expended in heating the binder and aggregates for mixing and compaction. The WCO is transformed into a binder through a maleinization reaction at 220 °C, incorporating maleic anhydride into the WCO. The maleinized waste cooking oil (MWCO) exhibits significantly higher viscosity compared to the waste cooking oil. This MWCO can partially replace bitumen in hot, or cold mixes. The study involves the mixing of 10, 20, and 40 % by weight of the MWCO with respectively 90, 80, and 60 % of the 70/100 penetration grade bitumen. The mixed binder is successfully emulsified via the Atmo-agilis® colloidal mill. The emulsion, kept at 40°C, and 70°C, is subsequently examined using laser granulometry to evaluate the variation in particle size. The particle diameter measurements range from 0.1 to 1000 µm, with a prominent peak at approximately 5 µm. This approach can ascertain whether droplets remain stably suspended in the aqueous phase or progressively flocculate and ultimately coalesce, leading to the emulsion breaking. The findings demonstrate that the emulsions remain stable at 40 °C for more than a week; nevertheless, it destabilizes when stored at 70 °C after one day. This work highlights the methodology to move towards bio-sourced formulations for the road industry and address specific points of attention for building post-oil pavement.

Keywords: Waste cooking oil, maleinization, bio-based binder, bitumen, emulsion, pavement.

See Full Paper in the Proceedings.

Effect of Cement type on durability properties of concrete

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Abstract. Durability governs the service life of reinforced concrete, yet practice often relies on accelerated tests whose results are not consistently established across mixtures. This study presents a single, side-by-side assessment of commonly used durability indices obtained by accelerated tests such as the chloride diffusion coefficient, the migration coefficient from the rapid chloride migration test, bulk electrical conductivity, charge passed in the rapid chloride permeability test, initial and secondary sorptivity, and accelerated carbonation measured on the same concretes made with four cement types and two water to cement ratios.. A clear pattern emerges: migration and conductivity align most closely with the diffusion coefficient, reflecting their common dependence on pore connectivity, tortuosity, and degree of saturation. The rapid chloride permeability test, while convenient for screening, primarily reflects bulk electrical behavior and exhibits larger scatter and a weaker practical link to the diffusion coefficient, consistent with its sensitivity to pore-solution chemistry, specimen heating, and conditioning. This limits its use for quantitative design unless results are correlated to diffusivity and calibrated by binder family. Sorptivity and carbonation are not reliable predictors of the diffusion coefficient at the dataset level, but they remain essential for exposures governed by moisture cycling and carbon dioxide ingress and help interpret variability in durability properties other than diffusion. Binder composition systematically affects both magnitudes and correlations, while a lower water to cement ratio and increased curing age reduce conductivity and diffusion in a manner modulated by the reaction kinetics of supplementary cementitious materials. Overall, this work provides a binder-resolved, calibration-ready mapping from migration and conductivity to the diffusion coefficient within a single, consistent experimental framework to support performance-based service-life design.

Keywords: Concrete durability, Sustainable construction, Durability index, Supplementary Cementitious Materials.

See Full Paper in the Proceedings.

Impact of processing parameters on the mineralogy and conversion rates of waste-sourced sodium metasilicates

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Abstract

The application of soluble silicates in the development of mineral-based construction materials has attracted considerable attention in recent years, particularly for their role in the alkaline activation of aluminosilicate binders. To meet environmental and economic imperatives, future production of soluble silicates for construction purposes should focus on (i) the valorization of mineral waste and secondary raw materials and (ii) the implementation of low-energy synthesis processes. This study contributes to these aims by systematically examining sodium silicates synthesized from two silica-rich waste sources—glass wool (MW) and glass waste (GW)—through thermochemical processing.

A series of physico-chemically well-controlled experiments was designed to evaluate the influence of key parameters such as waste composition, SiO_2/Na_2O molar ratio (modulus, M_s), reaction temperature and duration on the efficiency of transformation into soluble silicate powders. XRD and FTIR analyses showed that the M_s and amount of reaction water are the critical factors that determines both the extent of the reaction and the mineralogical characteristics of the products. Maximum conversion rates of 95 wt.% for GW and 78 wt.% for MW were achieved at M_s values of 0.79 and 0.78, respectively, with Na-metasilicates and Na-carbonates as the dominant crystalline phases.

Dissolution experiments with the synthesized products indicated rapid dissolution kinetics for all systems with $M_s < 1$, with peak concentrations of dissolved Si and Na achieved within 5 minutes of reaction. The highest concentration of dissolved Si was observed at M_s values of 0.89 (GW) and 0.87 (MW), corresponding to a mineralogical composition of 44 wt.% and 37 wt.% Na-metasilicates, 14 wt.% and 12 wt.% Na-carbonates, and an amorphous phase content of 40 wt.% and 51 wt.% for GW and MW systems, respectively.

Keywords: soluble silicates, mineral wastes, dissolution kinetics, synthesis setups

Low carbon, high performance additive solutions for pavements

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Abstract

In this paper, the life cycle assessment (LCA) of utilizing a functionalized polyolefin (FPO) as an additive in polymer modified bitumen (PmB) has been studied from a 'cradle-to-use' perspective utilizing SimaPro®. The assessment was made as per pavement construction in North India and included other additive solutions such as Styrene-Butadiene-Styrene (SBS). The LCA results indicate lower CO2 emissions with the functionalized polyolefin, especially derived from energy consumption differences during PMB manufacturing. Pavements were prepared as per PG 76-10 E requirements with different grades and network survey vehicle (NSV) data was gathered post multiple seasons of the pavement usage. The NSV data on pavements made with FPO additive indicated that fatigue, rutting resistance, and macro-texture roughness behavior met the demanding requirements as per standards.

Keywords

Low carbon, pavements, LCA, functionalized polyolefin, polymer modified bitumen, asphalt

See Full Paper in the Proceedings

Mechanical Performance Investigation of Mortar with Acid-Leached Sewage Sludge Ash

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Abstract. With the increase in population, water consumption is rising. This situation leads to increase in wastewater and decrease in usable water. While treating wastewater, there are residual materials such as sewage sludges. Among the possible management options, they can be incinerated. The output of the incineration process (sewage sludge ash) can be further treated to recover valuable products (e.g. phosphorus fertilizers), while leaving still some materials that need to be disposed of. Cement-based materials can be considered an alternative to contain this material as sustainable solution. In this study, sewage sludge ash was acid-leached with two different acids (HCl and H2SO4) to extract the phosphorus to be valorized in agricultural activities. The solid residue after acid-wet leaching constitutes approximately 90% of the ash and its recovery is important to reduce waste production. In this study, this material was considered as sand replacement (25%) in mortar. Two different mix designs for each material were examined. Since the ash residues at issue have a very high-water absorption capacity which hardly can be measured due to mud-like behavior when mixed with water, the first mix design was determined by adding water to the mixes calculated for ASR to replace 25% of the sand from the reference, to obtain the same workability as the reference. Through this method, cement dosage per unit volume actually decreased. In the second mix design, the cement amount was kept the same as in the reference mix, and half of the additional water of Mix Design 1 was used as additional water; workability was adjusted with a superplasticizer. This study examines five mixes tested for flexural and compressive strength at 7 days and 28 days. Also, 3 of these mixes were tested on the 56th day. A reduction in strength was observed in all mix designs compared to the reference mix. However, the second mix design with HCl leached sewage sludge features an acceptable strength decrease even with the increase in water amount in this study and can be deemed as suitable for practical applications.

Keywords: ASR, Mortar, Sand replacement

See Full Paper in the Proceedings.

CARBPON CALCULATOR FOR REDUCING EMBODIED CARBON FOOTPRINT OF HOME RETROFITTING

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Abstract

This paper presents selected findings from an investigation into quantifying the embodied carbon footprint of home retrofitting measures delivers by The Greater Manchester Combined Authority (GMCA) as a part of its ongoing grant-funded decarbonisation schemes. A Carbon Calculator has been developed to quantify the Whole Life Cycle (WLC) embodied carbon of several energy efficiency measures, such as solar panels, heat pumps and external/internal wall insulation. Whilst the embodied carbon data of the products for life cycle stages A1 to A3 (known as 'cradle-to-gate' stage) can reliably be known, the data for life cycle stages A4 and A5, and B to D are difficult to know. The present work reliably quantifies the WLC (i.e. life cycle stages A to D) embodied carbon footprint of a range of products used in retrofitting projects. The results show how the Carbon Calculator enables comparing different products of the same retrofitting measure per unit of energy saving, for example, different solar panels per one Watt of power and thermal resistance of different wall insulation measures per unit area of the wall. The work also shows the use of the developed Carbon Calculator for ranking different products based on their WLC embodied carbon per unit of performance, and to make decisions on the relative contribution of specific life cycle modules such as transformation of the products imported from overseas. The Carbon Calculator further enables identifying most significant life cycle module (or modules) of different products as per the whole life embodied carbon. The work also presents the significance of the life cycle stage D (i.e. recycling or reusing materials beyond the current life cycle) on WLC embodied carbon footprint, and how combinations of life cycle modules can be chosen to make reliable decisions on the embodied carbon impact of different energy efficiency improvement measures.

Keywords: Carbon-calculator, Embodied-carbon, Life-cycle-analysis, Retrofitting, Whole-Life-Cycle

Assessment methods and classification models for the reuse of reinforced concrete elements

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Abstract. Reuse in contemporary construction is mostly limited to down-cycling. This leads to unnecessary waste production and resource consumption, especially in case of concrete structures that are demolished and crushed despite having intact load-bearing components. The newly established, DFG-funded Collaborative Research Centre CRC 1683 aims to develop scientific methods for the *genuine* structural reuse of concrete elements, guided by sustainability principles [1]. Instead of uncontrolled demolition, the project promotes rational deconstruction into modules that can be characterized, refurbished, and reassembled. This approach seeks to fully reuse reinforced concrete elements that have served under various load and environmental conditions. Such reuse requires a reliable framework for assessing load-bearing capacity and durability in new service scenarios [2].

This study addresses key research questions to establish fast, economical, yet accurate characterization methods for extracted reinforced on concrete elements. A comprehensive experimental program is conducted for one first example of an extracted element to identify effective in-situ techniques, focusing primarily on non-destructive tests (NDT). Beyond structural features like reinforcement layout and concrete cover, NDTs are evaluated for their ability to detect flaws such as honeycombs, cracks, and reinforcement debonding. These tests aim as well to determine properties like concrete strength, and permeability.

The study explores correlations between in-situ measurements, NDT and destructive tests to develop reliable yet quick inspection strategies for assessing the element condition, reinforcement detailing and structural performance in the context of potential reuse.

Ultimately, the developed testing framework and inspection methods aim to support classification models for assessing reusability and predicting the remaining service life of reinforced concrete elements, enabling a more sustainable future in construction.

Keywords: reinforced concrete, structural reuse, non-destructive testing.

See Full Paper in the Proceedings.

MIX DESIGN, 3D-PRINTING AND SURFACE TREATMENT OF CEMENTITIOUS MATERIALS TO PROMOTE BIORECEPTIVITY FOR THE EUROPEAN FLAT OYSTER

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Abstract

Supporting a prosperous evolution for human society can pose a negative impact on earth's resources. The magnitude of impact is related to the type of practise. Overfishing and bottom trawling has extracted available hard substrates for oyster larvae to settle, leading to functional extinction of the European flat oyster (*Ostrea edulis*) in the North Sea. Cementitious mix design to promote bioreceptive concrete as maritime infrastructure or as stand-alone 3D-printed substrates may serve as a quick start to regenerate oyster reef ecosystems. Therefore, a mortar mix design with cement type CEM III/B 42.5, with sea sand and binder-to-sand ratio of 1:1, is modified by substituting 50 wt.% binder with oyster shell powder (OSP) and 50 wt.% sea sand with oyster shell (OS) fragments of 4-7 mm. In addition, a hybrid binder mix consisting of 15 wt.% CEM I 52.5, 20 wt.% fly ash, 10 wt.% GGBFS, 5 wt.% $CaCO_3$ and 50 wt.% sea sand, with addition of 2 wt.% sodium sulphate, is modified by substituting 50 wt.% sea sand with oyster shell (OS) fragments of 4-7 mm. Both mixes are casted and washed out to a depth of 4-6 mm, exposing the OS fragments on the surface of the material. Furthermore, the CEM III/B 42.5 is optimized to be suitable for 3D-printing. The obtained roughness, introduced with this layer-wise production technique or the exposed OS, is expected to enhance the bioreceptivity and is evaluated using Automated Laser Measurements (ALM). Other analysed characteristics are porosity, calcium carbonate content and pH. They are measured using vacuum water absorption, thermogravimetric analysis and ex-situ leaching with an Ag/AgCl electrode. To validate the influence of the material characteristics on bioreceptivity, 10 containers with substrate variations are filled with European flat oyster larvae to obtain lab-controlled settlement and survival rates on the tested substrates.

Acknowledgements

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Keywords: Cementitious, 3D-printed, mortar, bioreceptivity, oyster

Effect of Calcination Temperature on the Reactivity of Stubble Burnt Ash for MgO-Based Ternary Binder

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Abstract.
Stubble burnt ash (SBA), a silica-rich byproduct derived from agricultural residue, was evaluated as a supplementary cementitious material in MgO-based ternary binder system. SBA was produced through controlled burning at 500 °C, 600 °C, and 700 °C for 1 hour, with reactivity found to be highly dependent on calcination temperature. X-ray diffraction (XRD) analysis confirmed that SBA calcined at 600 °C possessed the highest amorphous silica content, while increased crystallinity was observed at 700 °C. A ternary mortar mix consisting of 50% ordinary Portland cement (OPC), 30% reactive MgO, and 20% SBA was prepared, incorporating a hydration agent to enhance MgO hydration. Mortar cubes (50 × 50 × 50 mm) were cast and tested for compressive strength and water absorption. The mix containing SBA calcined at 600 °C exhibited a compressive strength of 44.32 MPa at 28 days and water absorption of 0.86%. The mortar with SBA calcined at 700 °C showed reduced strength (30.43 MPa) and higher water absorption (1.85%) due to the presence of unreactive crystalline silica. M-S-H is the primary phase responsible for compressive strength, formed through the hydration of MgO and silica derived from SBA reported via XRD. These results demonstrate that SBA derived from stubble and calcined at 600 °C is more effective in enhancing the performance of the MgO-based binder system compared to SBA calcined at 500 °C and 700 °C.

Keywords: Hydration agent, Stubble burnt ash, MgO , M-S-H

See Full Paper in the Proceedings.

Investigating the use of biochar as an additive for climate neutral concrete

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Abstract**.** The incorporation of biochar as an additive in cementitious materials presents a promising pathway toward climate-neutral concrete. Biochar, a carbon-rich solid obtained from biomass pyrolysis, can act as a micro-filler, internal curing agent and long-term carbon sequestration medium. This study examines the influence of biochar particle size and cement type on the fresh and hardened properties of cement pastes and micro-concretes. Two biochar types with median particle sizes of D_{50} = 128 µm and D_{50} = 51 µm were incorporated with CEM I 42.5 N, CEM II/B-M 42.5 N, and CEM III/B 32.5 N cements. Flow spread, water demand, density, and compressive strength were evaluated. The results show that fine biochar particles significantly increase water demand and accelerate workability loss, whereas coarse biochar promotes better strength development. Among the binders, CEM III/B 32.5 N demonstrated the best long-term strength performance, suggesting synergistic hydration between slag and biochar-induced internal curing. These findings confirm that properly optimized biochar addition can improve mechanical stability while contributing to CO_2 sequestration in concrete systems.

Keywords: sustainability, carbon sequestration, climate-neutral, workability, additive.

See full Paper in the Proceedings

CHARACTERIZATION OF 3D-PRINTED CONCRETE AFTER 48 MONTHS OF NATURAL CARBONATION IN THE SWISS ALPS

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Abstract

With the rapid advancement of 3D-printed concrete (3DPC) technology in recent years, several large-scale structures have successfully been built. Nevertheless, the long-term durability of 3D-printed elements remains insufficiently assessed. Previous research has reported that 3DPC exhibits faster carbonation than conventionally cast concrete made with the same mixture. This raises concerns regarding reinforcement corrosion, as the higher porosity and layered geometry of 3DPC may reduce the protective capacity of the cover zone. These findings, obtained primarily through accelerated carbonation tests, provide valuable guidance for improving printing quality and estimating service life with respect to carbonation. However, to the best of the authors' knowledge, no investigations on natural carbonation in 3DPC have been reported to date.

This study examines 3D-printed specimens exposed to natural outdoor conditions for 48 months in the Swiss Alps. Microstructural characterization was performed on the carbonated and uncarbonated regions using MIP, SEM, and X-ray micro-computed tomography to evaluate pore-structure evolution. Carbonation coefficients were compared with those obtained under accelerated conditions (printed samples exposed to 4% CO_2) for the same mix, in order to assess whether conventional service-life prediction approaches remain applicable to 3DPC. In addition, a dynamic life-cycle assessment is presented, using the "Tor Alva"— currently the tallest 3D-printed building in the world (produced with the same mix design presented in this research) —as a case study to estimate the structure's potential CO_2 uptake and quantify the resulting reduction in carbon footprint due to carbonation.

Keywords: Natural carbonation; Microstructure; 3D-Printed Concrete; Durability, Carbon capture.

RECYCLED FINE AGGREGATES IN PLASTERING AND RENDERING MORTARS: FROM MORTAR- TO MASONRY-SCALE PERFORMANCE

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Abstract

The abstract should be less than 300 words.

The use of recycled fine aggregates is sometimes proposed for less demanding non-structural applications, such as in coating mortars for masonry. The potential of using recycled fine aggregates as complete replacements for natural siliceous sand in plastering and rendering mortars was examined through the development of new mortars incorporating recycled aggregates sourced from either concrete-based or mixed construction and demolition waste. The properties of fresh and hardened mortars, which included consistency, water retention, fresh bulk density, air content, mechanical strength, shrinkage, porosity, water absorption, and water vapour permeability, were assessed to understand their performance relative to natural aggregate mortars. For masonry-scale testing, plastering mortar was applied to an autoclaved aerated concrete block, while rendering mortar was applied to a clay block, and their adhesive strength and compatibility with the substrate were evaluated. At the mortar scale, the use of recycled concrete aggregates caused the highest water demand, leading to reduced mechanical strength, whereas mortars made with recycled mixed aggregates showed significantly improved compressive strength. However, the drying shrinkage of mortars with both types of recycled aggregates was up to four times higher than that of natural aggregate mortars. This likely contributed to reduced adhesion and compatibility with the substrate, along with the development of surface cracks on rendered wall specimens. Overall, the results indicate that recycled fine aggregates can constitute a technically viable replacement for natural sand in coating mortars, but their properties cannot be assessed solely at the mortar scale. In real coating mortar applications, the performance requires optimisation to achieve adequate compatibility with masonry substrates and to control shrinkage-related effects in plasters and renders.

Keywords: Recycled sand, coating mortars, mortar properties, masonry application

Lower the Carbon Footprint of Buildings: Comparison of Structural Retrofit and Recycling Concrete with Carbon Sequestration

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Abstract. The building construction sector in the UK is responsible for generating about 49% of the carbon emissions in the country, which is primarily due to the embodied carbon emissions generated from manufacturing construction materials such as concrete or steel. Reducing the embodied carbon is timely required to achieve the net-zero goal by 2050. To lower the carbon footprint of buildings, the circular economy principle has attracted significant attention from the industry, government and academia for its potential to effectively decarbonise the material manufacturing and building construction sectors. Different circular economy approaches are identified, including retrofitting end-of-life buildings to fit the new building requirements or creating the new buildings with materials recycled from the demolition of the end-of-life buildings. However, it is uncertain about the reductions in carbon footprint from using these approaches for buildings and the more effective approach for decarbonisation.
This research aims to investigate the reductions of environmental impacts achieved with the two approaches, as retrofitting existing buildings and recycling demolished concrete for new construction, to achieve higher environmental benefits. Comparative life cycle assessment has been conducted to analyse the life-cycle embodied carbon and other environmental impacts of the new building retrofitted from an existing case study building and that of the new building constructed with the concrete materials recycled from the demolition of the original building. Besides, the life cycle assessment for the new building constructed with recycled concrete materials also incorporates the use of carbon sequestration technology in the recycling process. The results demonstrate that the circular economy approach through structural retrofit provides better environmental performance due to the much lower consumption of new construction materials.

Keywords: Circular economy, Building Structural Retrofit, Recycling Concrete, Carbon Sequestration, Life Cycle Assessment.

See Full Paper in the Proceedings

Effect of drying at early age on the carbonation of ternary binder with high content in limestone filler

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Abstract. To reduce the environmental impact of cement production and to save energy, one solution is to replace clinker by supplementary cementitious materials (SCM) to design binary or ternary binder. However, the reaction kinetics of SCM are slower than clinker, leading to a delay in the development of the microstructure. Therefore, this study assesses the impact of drying impact at early age for concretes containing this kind of binder. Concretes with a W/B = 0.35 and ternary binder content of 350 kg/m^3 were assessed. The binders were composed of: 20% Ordinary Portland cement (OPC)/ 30% GGBS1/50% Limestone filler, 20% OPC/30% GGBS2/50% Limestone filler and 25% OPC/25% GGBS2/50% Limestone filler. The comparison was made with a reference concrete containing 300 kg/m^3 CEM III/A and a W/B = 0.50 (XC4 according to EN 206+A2/CN:2022). The concrete specimens were cured for 1, 3, 7 and 91 days. Then they were carbonated in accelerated conditions ([CO_2]=3%), according to NF XP P18-458. In addition to the carbonation kinetics, mercury intrusion porosimetry was performed before and after carbonation. The results showed that for a similar compressive strength class, concretes cured 91 days and containing ternary binders had a better resistance against the carbonation than the reference. For the concrete containing the ternary binder (20% OPC/ 30% GGBS1/50% Limestone filler), the effect of drying at early age on the carbonation kinetics was similar to the reference concrete.

Keywords: Drying, Carbonation, Limestone filler, ternary binder, MIP

See full paper in the proceedings.

THE EFFECT OF MAGNESIUM OXIDE AND CALCIUM OXIDE ON THE EARLY AGE HYDRATION AND SETTING OF LC3 PASTES

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Abstract. Limestone Calcined Clay Cement (LC3) has emerged as a promising low-carbon alternative in the cement and concrete industry. Incorporating expansive agents such as magnesium oxide (MgO) or calcium oxide (CaO) into LC3 formulations may offer additional sustainability benefits by mitigating shrinkage, enhancing crack resistance, improving self-healing capacity, and thereby extending service life. However, as LC3 is known for limited early-age strength development, it is essential to understand how these additives influence early-age hydration. Hence, this study investigates the influence of MgO and CaO on the early-age hydration behaviour of LC3 pastes. Initial and final setting times were determined using an automatic Vicat apparatus to assess stiffness evolution, while isothermal calorimetry was performed for 72 hours to evaluate hydration kinetics. Heat flow curves were analysed with a focus on the changes in induction period, the rate of cement hydration, energy release during the main hydration peak, and cumulative heat energy release. The results revealed that MgO significantly delayed both initial and final setting times and postponed the onset of the main hydration peak in LC3 systems. In contrast, CaO demonstrated accelerated and enhanced early hydration activity which explains its early stiffening effect. However, the study strongly emphasizes the importance of optimizing additive selection based on both early and long-term performance criteria for LC3-based cementitious systems.

Keywords: LC3, expansive agent, CaO, MgO, early-age hydration

See full paper in the proceedings.

Evaluation of Water Demand in Screed Mixtures Containing Secondary Sands

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Abstract. Since the secondary sands are extracted from multiple sources, their physical properties, such as particle size distribution, density, porosity, grain shape, and internal friction, are different from the natural river sands. These parameters impact the water absorption of the aggregates, and the workability and finishability of the screeds, as well as their hardened properties, such as compressive and tensile strength. The measurement of water absorption of secondary sands using the standard methods remains an open question, which makes it even more complicated to find the total water demand of the screed mixtures. Also, because screed mixes are relatively dry compared to conventional mortar or concrete mixes, their workability is difficult to define using standard methods used for mortar or concrete. In this paper, an effort has been made to predict the water demand of screed mixes based on the physical properties of secondary sands. Finally, the impact of water demand on compressive and tensile strength of hardened screed is observed and reported.

Keywords: Screed, Natural River Sand, Recycled/Secondary Sand, Workability, Finish-ability.

See full paper in the proceedings.

COMPARATIVE LCA OF CARBONATED CONSTRUCTION PRODUCTS CONSIDERING ASSOCIATED PERMANENT CARBON STORAGE AND WASTE TREATMENT FUNCTIONS

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Abstract

Enforced carbonation is increasingly explored as an alternative to conventional carbon capture and storage (CCS), offering the additional benefits of producing value-added materials for construction and recycling carbonatable waste streams. To discuss how this inherent multifunctionality affects the environmental performance assessment of carbonated construction products, this study presents a comparative life cycle assessment (LCA) of a Supplementary Cementitious Material (SCMs) derived from carbonated recycled concrete paste (RCP). The comparison is based on a functional unit of 1 tonne of composite cement containing carbonated RCP, along with the corresponding amount of CO_2 permanently stored and construction and demolition waste treated. This system is assessed against a reference scenario that delivers the same functions—composite cement with equivalent mechanical performance, CO_2 capture and underground CO_2 storage, and waste treatment. The system boundary includes the full life cycle, and different strategies are explored for handling multifunctionality, including system expansion and allocation. Uncertainties in the life cycle inventory are estimated and propagated to the Global Warming Potential results. Results indicate that carbonated RCP can provide superior climate performance relative to other SCMs. However, the extent of this benefit is influenced by the efficiency of the carbonation process, transport distances of the concrete waste, and—most critically—the carbon intensity of the substituted cement, which in turn depends on the clinker replacement rates achieved by the carbonated RCP and its counterparts. Allocation choices also determine LCA results. Our findings highlight the potential of carbonated construction products to reduce emissions, manage waste, and substitute carbon-intensive materials, while also demonstrating how methodological choices can significantly influence LCA results of carbonated construction products.

Keywords: Life Cycle Assessment, Carbonation, Recycled Concrete Paste, Supplementary Cementitious Material, Carbon Capture and Storage

Towards sustainable concrete: a case study on environmental performance, water, and energy use

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Abstract. This study presents a gate-to-gate environmental performance assessment of a ready-mix concrete production plant in Panama, based on twelve months of operational data. The aim is to evaluate the plant's environmental performance by quantifying resource use and emissions within its operational boundaries. Downstream and upstream processes, such as the production and transportation of raw materials and energy generation, are not considered in this study. The analysis focuses on water, electricity, and diesel consumption, direct CO_2 emissions, and effluent water quality. Monthly operational records were normalized on a per-cubic-meter basis for concrete production. Water quality was evaluated according to the DGNTI-COPANIT 24-99 regulation for treated wastewater reuse in Panama, and environmental aspects were linked to midpoint categories under the ReCiPe 2016 framework. Water consumption varied between 421.07 - 757.69 L/m³, electricity use ranged from 4.86 - 8.53 kWh/m³, and diesel consumption ranged between 3.54 - 6.78 L/m³. Direct emissions due to diesel combustion ranged from 9.94 - 19.04 kg CO_2eq/m³. These values fall within international ranges but show slightly higher water and energy intensity than benchmark studies. Effluent analysis revealed partial compliance with DGNTI-COPANIT 24-99, particularly for pH, turbidity, and total coliforms, emphasizing the need for improved treatment and monitoring, and the assessment of additional indicators. This gate-to-gate assessment provides the first plant-level baseline for Panama's concrete industry, identifying operational hotspots and opportunities for optimizing resource efficiency, improving wastewater management, and supporting national efforts toward sustainable concrete production.

Keywords: Water, Energy, CO_2 emissions, concrete production, Panama.

See full paper in the proceedings.

STRATEGIES AND PUBLIC POLICIES TOWARDS SUSTAINABLE CONCRETE

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Abstract

Concrete is the most consumed construction material, but its production, particularly cement production, accounts for approximately 7–8% of global CO_2 emissions and significant water and energy use. As the world intensifies efforts to combat climate change and promote sustainable infrastructure, international organizations and industry associations have developed strategic roadmaps to guide the transition toward more sustainable concrete production. These roadmaps propose a combination of technological, process-based, and policy-driven approaches to achieve net-zero emissions and resource efficiency in the sector. This study aims to examine the key strategies and public policy instruments proposed in leading international road maps for sustainable concrete. A qualitative, comparative policy analysis was conducted using document review and roadmap benchmarking. A total of 28 roadmaps were examined, including international partnership frameworks and national strategies from America, Europe, Oceania, and Asia. A comparative matrix was developed to classify strategies by decarbonization levers (e.g., clinker reduction, alternative fuels, energy efficiency) and to assess the presence and type of public policy instruments (e.g., standards, incentives, monitoring systems). Water-related impacts are still not considered, even though they are a priority on the agenda of many countries. The results show strong global convergence around strategies such as clinker substitution, use of alternative fuels, process optimization, and carbon capture technologies. Yet, the adoption of these measures depends heavily on policy support. Successful road maps integrate regulatory, economic, and institutional tools to drive implementation. Public policy instruments commonly include updated technical standards, financial incentives, lifecycle-based tools (e.g., EPDs), and monitoring frameworks. The study concludes that decarbonizing the cement and concrete sectors requires integrated policy frameworks that combine regulatory, economic, and technological instruments. The roadmaps reviewed offer strategic frameworks that enable countries and industries to develop context-appropriate pathways toward low-carbon, sustainable construction.

Keywords: Sustainable concrete; Public policy; Decarbonization strategies; Roadmap analysis.

ARTIFICIAL AGGREGATES FROM WASTE PELLETIZATION TO PROMOTE CONCRETE SUSTAINABILITY

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Abstract

The use of artificial aggregates manufactured from waste and by-product materials, as an alternative to natural aggregate, has attracted considerable research interest.

Extensive research has been conducted to pre-process or pre-treat different source of wastes to be used as raw materials for artificial aggregates (AAs) production. In this experimental work artificial aggregates have been manufactured by means of cold-bonding granulation. Cold-bonding pelletization is carried out through a rotating plate device allowing the formation of pelletized aggregates from waste materials through gravitational and centrifugal forces.

In addition to traditional single step cold bonding granulation, a double pelletization was carried out to reach AAs with improved properties. In the one-step pelletization the waste is incorporated within the binding matrix, while in the two-step pelletization, a second incapsulation is made in order to obtain AAs embedded within an outer shell likely able to improve both their technological and leaching properties.

Several concrete mixtures were designed by alternatively adding either single-bond AAs or double-bond AAs at different dosages (0% - 10% - 20% and 30% replacement by weight of aggregate). Then, several Artificial Aggregate Concretes (AACs) specimens were manufactured in order to characterize fresh concrete rheological behaviour as well as hardened concrete mechanical and physical properties. In detail, besides to fresh consistency tests, density evaluations were carried out at fresh and hardened state; compression, indirect tensile and bending tests were performed at both early age and long term (3, 7, 28, 90 and 180 days of curing); both secant static and dynamic elastic modulus by ultrasonic pulse at 28 days of curing were evaluated. Moreover, free drying shrinkage tests (up to 180 days of curing) under 50% R.H. and 20°C temperature were carried out. All the designed AACs, including those prepared with 30% double-bond pelletization, achieved adequate mechanical performances for structural use in building.

Keywords: Artificial Aggregates; Artificial Aggregate Concretes; Mechanical Tests; Sustainable Building; Sustainable Concrete; Waste Pelletization.

IMPACT OF CARBONATION ON MECHANICAL PROPERTIES AND MICROSTRUCTURE OF BLENDED CEMENTITIOUS MATERIALS WITH HEAVY REPLACEMENT OF MINERAL SCMS

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Abstract

Low-carbon blended cementitious materials are increasingly sought to reduce the carbon footprint of construction, in line with global sustainability policies. However, carbonation-induced deterioration is a pervasive durability concern, and data on the carbonation performance of such blended cements—especially at high replacement levels—remain limited. This study investigated the use of silica fume (microsilica) and ground granulated blast-furnace slag (GGBFS) as supplementary cementitious materials (SCMs) to partially replace ordinary Portland cement (OPC). Two types of binder systems were evaluated: (i) high-replacement blends with up to 90% OPC replaced (10%SF+80%GGBFS, Group G1), and (ii) moderate-replacement blends with up to 50% OPC replaced (10%SF+40%GGBFS, Group G2). Fresh properties were characterized by Vicat setting time and isothermal calorimetry to assess setting and hydration behaviors. Paste and mortar specimens (40×40×160 mm prisms) were cast and cured sealed for 91 days. Thereafter, samples were preconditioned at 20 °C and 60% relative humidity (RH) for 3 months before accelerated carbonation exposure (1% CO_2, 20 °C, 60% RH) until substantial carbonation depths were achieved. Mechanical testing (flexural and compressive strength) was conducted on specimens before and after carbonation (two carbonation periods). Pore structure evolution was characterized by water accessible porosity, Mercury Intrusion Porosimetry (MIP), and Scanning Electron Microscopy (SEM) with backscattered electron imaging. Changes in phase composition were analyzed by Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), and Thermogravimetric Analysis (TGA), and carbonation shrinkage of the 90% replacement ternary binder was also monitored. Results show that before carbonation, Group G1 (high-SCM) exhibited higher flexural but lower compressive strength compared to Group G2 (moderate-SCM). After carbonation, G1 experienced reductions in both flexural and compressive strength, whereas both strengths increased in G2. Microstructural analysis indicated that in G2, portlandite in the matrix provided a buffer against carbonation, leading to $CaCO_3$ precipitation that refined the pore structure. In G1, by contrast, limited portlandite buffering allowed carbonation to attack the C–S–H/C–A–S–H gels directly, resulting in a coarser pore structure. These findings highlight the distinct carbonation behaviors of high- versus moderate-SCM systems and can inform the design of durable low-carbon cementitious materials.

Keywords: Carbonation, low-carbon cement, mechanical strength

Assessing Climate Impacts of Supplementary Cementitious Materials in Cement: An LCA based Global Warming Potential Perspective

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Abstract. Cement is a fundamental building material of modern infrastructure. Though it underpins global development, it is fueling the climate crisis with massive carbon emissions. This concern has been addressed here by performing a comprehensive cradle to gate life cycle assessment (LCA) study on manufacturing 1 Mega tonne Ordinary portland cement (OPC), Portland pozzolana cement (PPC), Portland slag cement (PSC), and limestone calcined clay cement (LC^3) for Indian geography to capture the large-scale environmental impact of the industry. The comparative LCA study performed incorporated ISO 14040, ISO 14044 standards, the latest Ecoinvent database for life cycle inventory (LCI), and Simapro PhD version software for life cycle impact assessment (LCIA). Individual product assemblies of different cement systems are exclusively designed considering transportation, electricity, coal, clinker production, infrastructure, incorporation of Supplementary Cementitious Materials (SCMs) such as fly ash in PPC, ground granulated blast furnace slag (GGBFS) in PSC, and limestone, calcined clay in LC^3. Global warming potential (GWP) is calculated as per the Intergovernmental Panel on Climate Change (IPCC) 2021 method over a time horizon of 100 years. GWP of OPC is estimated to be 0.88 million tonneCO_2eq, which is substantially high due to its high clinker content. GWP fossil-dominated ~99% greenhouse gas (GHG) emissions than biogenic, land transformation. Majorly, carbon dioxide (CO_2) and very little methane (CH_4) emissions arising primarily from clinker production, electricity, hard coal, and processing of GGBFS in PSC, clay calcination in LC^3 are found responsible for the high GWP of cements. Blending cements with SCMs such as 30% fly ash in PPC reduces GWP by 30%, 60% GGBFS in PSC by 47.4% and 45% limestone, calcined clay in LC^3 by 35.8% respectively. Clinker reduction is found to be a key parameter for improving the environmental sustainability of cement. Blended cements demonstrate reduced GHG emissions, with PSC exhibiting the lowest GWP. Further lowering in GWP may be achieved by incorporating more of renewables – solar, wind, bio-fuel, and alternative fuels in cement production and SCM processing.

Keywords: Life cycle assessment, supplementary cementitious materials, GWP, OPC, LC^3

See full paper in the proceedings.

Approaches for the integration of socio-economic parameters in the life cycle assessment of construction materials and structures

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Abstract. To foster sustainable human settlements, it is essential that design, construction, and operation of structures minimise environmental impacts and advance social equity and economic viability in parallel. However, while environmental and carbon footprints are matter of intensive research to date, little effort has been put on understanding the "socio-economic footprint" consequences of using materials and structures. Historically, materials' structural performance parameters like strength and durability were major assessment criteria. Today, in the light of increasing climate awareness, environmental aspects have become pivotal in addition to safety and performance. However, for sustainable habitat development, there is more to materials than efficiency and environment. There is also a socio-economic component. Even with lowest carbon materials, structures can be wasteful, if they are not built for people, as their use phase is limited. Materials and architecture, thus, must secure identity, local livelihoods, and longevity of use. However, unlike technical parameters that are clearly defined and more like economic parameters, these "soft" criteria are difficult to define, and in addition there is a variety of aspects to consider.
The paper discusses the challenges linked to the development of assessment criteria for a socio-economic footprint with a special focus on the wealth and power gap between differently industrialised countries. Different concepts will be discussed in context of their suitability for life cycle assessment. Eventually, approaches for clearly identifiably parameters based on economic numbers, numbers of beneficiaries and knowledge gain will be proposed as baseline for future research and development.

Keywords: Socio-economic footprint, sustainability, LCA, supply chains.

See full Paper in the Proceedings

EFFICIENT DIRECT AIR CAPTURE CO2 USING STEEL SLAG

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Abstract

Direct Air Capture (DAC) is pivotal in reducing atmospheric CO_2 levels to combat climate change, necessitating a balance of capture efficiency, energy use, cost, and scalability. This study introduces an innovative DAC strategy utilizing steel slag and triisopropanolamine (TIPA) to capture CO_2 from the air while repurposing solid waste. The findings reveal that steel slag achieves a carbonation degree exceeding 10% within 6 hours, with a CO_2 absorption rate surpassing 95% at airflow rates below 2.5 L/min, demonstrating significant potential for DAC. During the process, calcium-containing mineral phases—CaO, $Ca(OH)_2$, $C_{12}A_7$, and C_2F—react to form calcite and Fe-Al gels, enabling permanent CO_2 sequestration. Moreover, the air carbonation rate is governed by CO_2 concentration, the dissolution and precipitation of calcium in solution, and the hydration-carbonation pathways of solid particles. And TIPA enhances the chemical environment, exposes reactive sites, and facilitates ion migration. The resulting carbonated slag exhibits improved stability, making it suitable for diverse industrial applications, such as a supplementary cementitious material or soil conditioner. This approach offers a promising pathway for integrating solid waste utilization with effective DAC carbon sequestration.

Keywords: Steel slag, DAC, Carbonation, Calcite, TIPA

LINKING RCA MOISTURE STATE AND ABSORPTION BEHAVIOUR TO THE EFFECTIVE W/C RATIO AND MECHANICAL PERFORMANCE OF RECYCLED CONCRETE

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Abstract

The use of recycled concrete aggregates (RCA) reduces reliance on natural aggregates (NA) and diverts demolition waste, offering clear environmental benefits. However, RCA differs from NA in its high porosity and slow saturation behavior. While NA typically reaches a saturated surface-dry (SSD) state within minutes, RCA requires more than three days to fully saturate. This time-dependent absorption introduces major uncertainty in recycled aggregate concrete (RAC), as the initial moisture state of RCA governs water exchange during mixing, thereby altering the effective W/C, ITZ formation, and mechanical performance. Despite extensive research, there is still no unified understanding of (i) how water uptake during mixing affects the effective W/C ratio, and (ii) how this effect depends on RCA origin and production method. This study addresses these questions through a controlled experimental program. Four types of RCA were produced from two distinct parent concretes using two recycling techniques, resulting in aggregates with different porosity and absorption rates. Each RCA type was washed, oven-dried at 75 °C, and pre-wetted to five moisture states: 0 % (oven-dry), 20 % (5 min), 60 % (30 min), 80 % (4 h), and 100 % SSD (72 h). The effective W/C ratio of the hardened paste was quantified to evaluate water migration and hydration. Microstructural analyses of the ITZ were performed using backscattered electron (BSE) imaging, energy-dispersive X-ray spectroscopy (EDS), and nanoindentation, while macro-scale performance was assessed through compressive strength, splitting tensile strength, and elastic modulus at 28 days. Results show that the optimal RCA moisture state depends not only on the water control strategy but also on the inherent absorption behavior determined by parent concrete and recycling technique. Differences in moisture state produced clear variations in ITZ density, microhardness, and hydration degree, leading to corresponding changes in mechanical properties. These findings demonstrate that tailoring RCA pre-wetting to its absorption kinetics provides a practical framework for balancing water availability, ITZ development, and RAC performance, enabling more reliable and sustainable concrete production.

Keywords: water compensation, water absorption rate, effective W/C ratio, moisture state, recycled concrete aggregate, recycled concrete

DEVELOPMENT OF A CARBON-SEQUESTERING ADDITIVE FROM WASTE PLASTIC FOR MAXIMIZING CARBON SEQUESTRATION IN CEMENTITIOUS BINDERS

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Abstract

Waste reduction techniques for plastic have become a matter of global concern. Existing techniques, such as incineration and recycling, have demerits related to the low-end product value and waste leakage of solid residues into the natural ecosystem. Therefore, an upcycling route is proposed via thermochemically activating the solid residue to improve its physicochemical properties and incorporating it as an additive in construction materials. This domain has a dearth of investigation, unlike biochar (not thermochemically activated), and evolves as a research gap. The study focuses on the incorporation of produced activated carbons (AC) in the temperature range of 550–750 ℃, in cementitious binders. AC possesses a brittle character at a higher temperature with a hierarchical pore structure, containing 62% micropores (<2nm), suitable for CO_2 uptake by the material. Further, the developed functional groups, like -COOH and -OH groups, add to the net CO_2 uptake through chemisorption mechanisms. The presence of local pore networks and surface moieties in AC affects the engineering properties of cement-AC binders. A retardation in hydration peak by ~2h was observed on the addition of AC in cement binders. There was a decline in compressive strength upto 30% due to the amorphous nature of AC at 28d. CO_2 sequestration improved in cement-AC mixes compared to the control mix (no AC) due to higher CO_2 trapping by functional groups and formation of new diffusion pathways by AC incorporation. Similarly, shrinkage characteristics showed a reduction of 12% at early ages and upto 40% higher at later ages compared to the control. The CO_2 sequestration through mineralization and uptake improved by ~30% and higher AC replacements (upto 10%), can reduce total CO_2 emissions by 12–15% compared to the control mix. Further investigations are needed to fully realize the benefits of incorporating AC as a carbon-sequestering additive in construction materials.

Keywords: Plastic waste; Activated carbon; physicochemical properties; carbon-sequestration; cementitious binders

Modifying the hydration of blast furnace slag rich blended Portland cement by layered double hydroxides addition

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Abstract. Ground granulated blast furnace slag (GGBFS) has been widely used as a Portland cement replacement in concrete production. However, due to its intrinsic slow early hydration, GGBFS-rich (>50wt.%) Portland cements can exhibit delayed strength development, which limits the content of GGBFS used in concrete mix designs in engineering practice, therefore higher GGBFS are not typically utilised in industrial practice. In this study, it was investigated the effect of adding a Mg-Al layered double hydroxides (LDH) with a hydrotalcite type structure, on the hydration and mechanical performance of high-volume GGBFS (80 wt.%) blended Portland cement paste. The addition of LDH can effectively accelerate the early hydration of GGBFS blended cement. By adding 5 wt.% of LDH relative to the binder content, the compressive strength of GGBFS-blended Portland cement mortar was improved by about 10% after 1 day of curing, compared to the reference. Thermodynamic modelling, under the assumption that LDH primarily affects GGBFS reaction at later curing ages, indicated that LDH-addition promotes the generation of aluminium substituted calcium silicate hydrate (C-(A)-S-H) type gels and monosulphate, thereby enhancing strength development. This study demonstrates the potential of Mg-Al LDHs additions to control hydration kinetics and early age strength development of GGBFS-rich blended Portland binders.

Keywords: blast furnace slag, blended Portland cements, layered double hydrates, hydration, compressive strength

See full paper in the proceedings.

Novel Bio-based Fibre Board Based on Elephant Dung and Bone Glue

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Abstract. In this study the potential of bone glue and dried fibres of Asian, African, and washed Asian elephant dung to manufacture fibre boards is investigated. Bone glue contents in this research were set at 20 wt%, 25 wt% and 30 wt% based on dry weight particles. Using a pressure of 4 MPa at room temperature, fibre boards measuring 200 x 350 x 10 mm were produced. The optimum properties were achieved at a bone glue content of 30 wt%. These boards achieved a maximum flexural strength of 15.4 MPa.

Keywords: elephant dung, bone glue, bio-based material, fibre board.

See full paper in the proceedings.

CONTROLLING FACTORS OF CRACK HEALING DEPTH IN MICROBIAL-BASED SELF-HEALING CONCRETE

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Abstract

Microbial based self-healing concrete technology is one of the most promising concrete self-healing technologies because of its durability, compatibility, and environmental friendliness. However, currently the microbial self-healing technology mainly acts on the surface of cracks, and the internal healing efficiency is too low, resulting in a low recovery rate of the mechanical properties of concrete, which has become a bottleneck in the practical application of this technology. In this study, firstly, the physicochemical characteristics of the crack area were examined, and the influence of the components of the self-healing unit on the physicochemical characteristics of the crack area was investigated. Then the in-situ bacterial behavior, including spore germination, revival of urease activity and carbonate precipitation, at different crack depths was comprehensively studied. Results have shown that pH and dissolved oxygen are the main controlling factors for the uneven distribution of the bio-precipitates. The added soluble Ca^{2+} source has limited contribution on the increase of the Ca2+ in the crack. Further optimization of the self-healing unit is suggested to focus on the adjustment of crack pH and increase of dissolved oxygen.

Keywords: pH gradient, oxygen distribution, Ca^{2+} dissolution, spore germination, revival of urease activity, crack depth.

Meta-Design: A Multi-Paradigm Active Learning Framework for Inverse Design of Sustainable Cementitious Materials

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Abstract

The accelerated development of sustainable cementitious materials, including supplementary cementitious materials, alkali-activated binders, and low-carbon concrete systems, requires efficient exploration of high-dimensional compositional design spaces under severe experimental budget constraints. Traditional trial-and-error approaches and purely data-driven surrogate modelling strategies often struggle in low-data regimes that characterize early-stage materials discovery.

We introduce **Meta-Design**, a web-based active learning platform for data-efficient inverse design of cementitious materials under multi-objective constraints. The platform implements a unified decision-making architecture that integrates three complementary paradigms: (i) classical surrogate-based active learning using uncertainty-aware models and acquisition functions to balance exploration and exploitation; (ii) Large Language Model (LLM)-assisted experimental suggestion, where domain knowledge embedded in pre-trained LLMs is leveraged to propose candidate formulations through contextual reasoning; and (iii) a Hybrid mode that fuses statistical utility estimates with semantic alignment signals derived from LLM guidance within a configurable weighted framework.

Unlike conventional active learning systems that rely exclusively on numerical surrogates, Meta-Design explicitly incorporates language-based domain priors as a parallel decision signal. This enables informed candidate selection in low-label settings while maintaining rigorous uncertainty quantification and diversity-aware batch selection. The platform supports multi-objective optimization with user-defined targets (e.g., strength, workability, CO_2 footprint), constraint handling, and interactive visualization of the evolving design space.

Meta-Design provides materials scientists with a flexible digital laboratory for experiment planning, enabling transparent comparison of ML-driven, LLM-driven, and hybrid decision strategies within a single operational environment. The tool is designed to accelerate hypothesis generation and reduce experimental overhead in the development of next-generation sustainable cementitious systems.

Keywords: active learning, inverse design, cementitious materials, large language models, multi-objective optimization.

Accelerating Sustainable Material Development with SLAMD: Case Studies Using Recycled Materials

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Abstract. As part of the EU-funded Reincarnate project, BAM has developed an AI-driven platform—**SLAMD** (Sequential Learning App for Materials Discovery), to accelerate sustainable material development through iterative laboratory testing, experimental validation, and data-driven optimization. SLAMD has reached TRL-6 and is currently being applied in two industrial case studies: one with a recycling company specializing in construction and demolition waste, and the other with a major manufacturer of cement-based building materials. In the first case, SLAMD is used to optimize composite cements incorporating recycled concrete fines and glass waste. In the second, it supports the development of formulations using processed concrete waste as aggregate, targeting performance across five exposure classes. By integrating SLAMD, both partners aim to rapidly identify optimal material compositions that balance mechanical performance, ecological footprint, and economic viability.

Keywords: Data-driven Design, Sustainable Materials, Recycled Material.

SUSTAINABLE CEMENT STARTS IN THE LAB

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Abstract

The development of sustainable cementitious materials increasingly relies on laboratory-scale processing routes that enable precise control of particle size, homogeneity, and material integrity. This contribution presents a comprehensive overview for the sample preparation including grinding, activation, and characterization of cement, clinker, supplementary cementitious materials (SCMs), and alternative raw materials. Emphasis is placed on mechanical size reduction strategies, abrasion control, and the choice of the most suitable equipment e.g. to prevent dust formation as key factors for reliable downstream analysis.

The presentation covers pre-crushing and fine-grinding of hard, brittle, soft, elastic, and fibrous materials using different milling techniques. Practical examples illustrate sample preparation routes for the above-mentioned samples. Mechanical clay activation (MCA) is highlighted as an approach to enhance the reactivity of calcined clays, demonstrating laboratory-scale activation under controlled milling conditions. In addition, modern air jet sieving is presented as an efficient method for particle size classification of fine cementitious powders, offering fast analysis, high accuracy, and digital data evaluation.

Overall, the contribution demonstrates how systematic laboratory processing - from crushing and grinding to activation and sieving - forms the foundation for the development and assessment of sustainable cement formulations. The outlined methods support reproducible research and provide scalable insights relevant to both academic studies and industrial applications in low-carbon cement development.

Keywords: Grinding, Homogenization, clay activation, sieving, sample preparation



BUILDINGS:

assessment

preservation

rehabilitation

strengthening

energy

indoor climate

A digital perspective on Architectural Heritage assessment and management: as-it-is BIM for heritage buildings

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Abstract. New digital technologies such as building information modelling (BIM) enables addressing complex tasks for sustainable management of Architectural Heritage. BIM models allow integrating historical, technical and service conditions, facilitating management plans suitable to social, cultural, and economic value of Architectural Heritage. However, the unique requirements of Architectural Heritage need tailor-made solutions for BIM modelling techniques.

This study aims to implement a methodology for creating BIM models that include historical, technical, service data and tailor-made materials for Architectural Heritage Management (7D BIM). This approach includes the identification and selection of a case study building located on the Historic Campus of the University of Alcalá, World Heritage Site by UNESCO; a digital base model on the current state; data collection of restoration, conservation and retrofitting actions carried out; in-situ measurements of historic and repair materials by non-destructive testing (NDT); monitoring indoor and outdoor environmental conditions; and laboratory experimental simulations of functionalized repair mortars suitable for refurbishment.

This methodology may provide essential knowledge about digital repository of Architectural Heritage Model and in-situ data measurements to support decision-making regarding habitability, energy efficiency and conservation in heritage buildings to fulfil the nowadays reuse requirements.

Keywords: Digital model, Architectural Heritage, Historic construction, In-situ data collection, Functionalized repair mortars, Service Conditions.

See Full Paper in the Proceedings

Experimental and numerical thermal assessment of 3D printed cement-lime mortars for multilayer architectural enclosures

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Abstract. The transition towards sustainable construction hinges on minimizing carbon emissions through innovative techniques and the integration of renewable, bio-based components in building materials. This study analyses experimentally and numerically the thermal performance of 3D printed cement-lime mortars with microencapsulated Phase Change Materials (PCM) and Cellulose Fibers for architectural applications in multi-layered building enclosures. Mortars with and without 20% of PCM by volume and fibers were compared. A thermal evaluation was carried out on multilayer specimens with a mortar layer plus a thermal insulation layer, applying cooling-heating dynamic cycles using a climate chamber. Two types of mortar specimens were compared: a cast-in mold plate and a 3D-printed plate. The set-up produced a one-dimension heat flow, perpendicular to the multi-layered specimen. Based on the experimental results, a computational model for transient heat transfer and thermal energy storage was proposed. Assuming ideal homogeneous thermal conduction between layers, a one-dimensional heat conduction finite element model was implemented, providing a framework for comparison between simulated and experimental results. The comparison allows a better understanding of the tested mortars thermal performance.

Keywords: Cement-lime mortar, 3D-printing, PCM, Cellulose fibers, Thermal performance, FE modelling.

See Full Paper in the Proceedings

High thermal performance lightweight mortars with bio-based PCM for 3D printing architectural applications

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Abstract. The development of sustainable construction materials can be addressed by incorporating bio-based components, improving energy efficiency, reducing carbon footprint and digitalizing the construction process. This study investigates the design of lightweight 3D printable mortars with reduced contents of cement and two types of microencapsulated bio-based phase change materials (PCM) for architectural applications. An expanded glass lightweight aggregate (EGA) was used for replacing part of the sand to improve the mortar's thermal insulation capacity. The aim was to design building materials with improved energy efficiency and thermal energy storage capacity. The mortars' rheological properties were assessed by using a flow table and vane tests. Cement hydration and mechanical properties' development were monitored with isothermal calorimetry and fresh compression tests. Finally, hardened thermal performance and physical and mechanical properties of the mortars were evaluated. The results of this study could contribute to boost the design of 3D printable mortars with improved thermal performance suitable for architectural applications.

Keywords: 3D Printing; Cement-based Materials; Phase Change Material; Lightweight aggregate; Energy Storage.

See Full Paper in the Proceedings

NANOMATERIALS BASED ON SEMICONDUCTOR METAL OXIDES TO IMPROVE INDOOR AIR QUALITY: DEPOLLUTION AND DETECTION

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Abstract

Improving indoor air quality (IAQ) is currently one of the major concerns of industrialized countries, especially since the introduction of energy efficiency measures in buildings. Focusing only on energy objectives can lead to a deterioration in other parameters of the built environment, such as comfort and IAQ. The aim of our research work was to develop functional materials to improve IAQ by reducing the concentration of gaseous pollutants and detecting these pollutants. The first step in this work was to synthesize gold (Au)-decorated ZnO using the photodeposition technique. Its photocatalytic performance in degrading NO_2 under visible and UV light at a laboratory scale was then assessed and compared with bare oxide ZnO and TiO_2 P25 (the reference photocatalyst). The results showed higher NO_2 degradation by Au/ZnO than by ZnO and TiO_2 P25, particularly under visible light. Characterization by electron spin resonance (ESR) highlighted a higher charge generation (electron and hole) for the Au/ZnO material favoring the formation of $OH^{\bullet}$ radical and thus better mineralization of NO_2 to NO_3^-. The second step of this work involved evaluating the detection capability of metal oxide semiconductor (MOS) sensors by comparing their response in terms of electrical resistance to the concentration value given by a reference analyzer operating by chemiluminescence. Two homemade MOS sensors were tested, differing in the metal oxides used for the sensing layers: a mono-layer sensor composed of WO_3 and a double-layer sensor composed of SnO_2/WO_3. The results showed that both sensors were sensitive to NO_2 concentrations between 100 and 400 ppb with electrical resistance values (in Ohms) corroborating well the concentrations (in ppb). In addition, the SnO_2/WO_3 sensor proved to be more suitable for monitoring NO_2 concentration during the photocatalytic remediation process due to its higher selectivity for NO_2.

Keywords: Indoor air quality, NO_2, photocatalysis, air depollution, sensor.

Climate-Resilient Building Envelopes: Comparative Energy Performance of Mycelium-Bound Composites (MBC) and Conventional Insulation Materials

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Abstract. Projected global climate change is expected to significantly affect environmental conditions, characterized by elevated ambient temperatures and increased solar radiation. These shifts are expected to result in higher cooling energy demands for buildings while reducing the requirements for space heating. Hence, it is imperative that building skins adapt to the changing climate and sustainability needs of the future. Emerging materials such as mycelium-bound composites (MBC) show promise as a sustainable alternative to conventional building materials. This study aims to evaluate the performance of MBC as an internal thermal insulation material in residential buildings compared to traditional insulation materials. A case study was conducted on a representative residential building in New Delhi, India, in a composite climate zone. A digital model of the selected building was created in DesignBuilder (version 7.3.1.003), integrated with EnergyPlus (version 9.4), to perform energy modelling for different external wall envelope systems, including autoclaved aerated concrete (AAC) blocks, dense concrete blocks, fly ash bricks, and conventional burnt clay bricks. MBC was evaluated as an internal thermal insulation in a residential building alongside expanded polystyrene (EPS), mineral wool, sawdust, and rice husk. Cooling and heating demands were analyzed for thirty-eight configurations of external walling systems and insulation types. The results suggest that cooling and heating demand could change within the ranges of +10.7% to -21.8% and +7.9% to -19.0%, respectively, for all configurations compared with the W1 configuration, i.e., a conventional burnt clay brick wall without insulation. The W23 configuration, i.e., the mycelium composite insulation placed on the interior side of the AAC block wall, performed better in energy efficiency than the W29 configuration, i.e., the mycelium composite insulation sandwiched between AAC blocks. The findings suggest that design strategies for bio-based insulation materials must consider optimal positioning within wall systems to maximise their potential.

Keywords: Mycelium-Bound Composites, Sustainable, Thermal Insulation, Energy Efficiency, Composite Climate

See Full Paper in the Proceedings

Investigating optimal wall to window ratio based on building orientation for traditional buildings in Malawi

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Abstract.

Exploring the optimal Window Wall ratio is essential for rural and traditional buildings in Malawi to achieve adequate and resilient housing for the rural communities. Thermal comfort is crucial in providing sufficient housing and sustainable indoor environments for human development and existence. Two traditional dwellings at Katola Village in Rural Lilongwe District were selected to be assessed, and simulation studies were conducted to achieve optimum Window Wall ratio design for traditional houses in Lilongwe, Malawi. A building model was developed to simulate the optimal Window to Wall ratio, and 18 building orientation variations were assessed at 20° increments from 0° to 340°. Additionally, the Window to Wall ratio range selected was from 10% to 90%, while 0% and 100% were eliminated as extreme ratios. Three primary criteria for each Window to Wall ratio and building orientation assessment were used: air temperature, air velocity, and daylight factor. A mean score was developed using international building codes to evaluate how the three criteria impacted indoor thermal comfort for each building orientation and Window Wall ratio. The intersection point of the three criteria was used to determine the optimal Window Wall Ratio for the model building. For accuracy of study data, field measurements and simulation data were correlated for cross-validation for this study. A previous survey of Malawi addresses optimizing an urban dwelling house, but very few studies have been done on traditional housing. The results show that the optimal Window Wall Ratio is between 30% to 50%, and the optimal building orientations for the South are Southeast (160°) and Northwest (340°) for North directions.

Keywords:

window-to-wall ratio; building orientation; thermal comfort; optimal; traditional dwelling; Malawi

See full Paper in the Proceedings

Evaluation of the Influence of Microencapsulated PCM on the Mechanical, Durability, and Thermal Performance of Sustainable Cementitious Mortars

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Abstract

This paper reports the results of an experimental program on sustainable cementitious composites made with microencapsulated phase change materials (MPCMs) to enhance thermal energy storage. The study focuses on the development and evaluation of cement-based mortars using river sand as fine aggregate and incorporating various MPCM contents (0%, 10%, 20%, and 30% by total mortar volume). The main objective was to investigate the mechanical and durability performance of these mixtures, along with the thermal behavior. Tests conducted included true and bulk density, particle size distribution and water absorption measurements. Mechanical testing was carried out to evaluate the influence of MPCM on compressive and bending strengths. The MPCM used in the study has an apparent solid density of 0.80 g/cm³ and a latent heat of 160 kJ/kg. According to the results, mechanical strength decreased with increasing MPCM content, and in the 30% MPCM mix, values dropped to below 50% of the reference. Regarding durability, water absorption in the 20% MPCM mix was lower than the reference, but increased at 30%, exceeding the reference value. This trend may be attributed to matrix compactness disruption due to the high MPCM content. Furthermore, the average mixture (20% MPCM) demonstrated significant thermal energy storage capacity compared to the reference.

Keywords: Phase Change Materials; Microencapsulation; Durability; Mechanical Properties; Thermal Energy Storage; Sustainable Mortars.

See Full Paper in the Proceedings.

MULTI-CRITERIA OPTIMIZATION OF A LOW-CARBON THERMAL INSULATION MORTAR FOR SUSTAINABLE BUILDING RENOVATION

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Abstract
This work reports the optimization of a binder for use in low-carbon Thermal Insulation Mortar (TIM) composed of a non-commercial pozzolanic binder and expanded glass beads. A multi-criteria design approach was adopted to optimize the pozzolanic binder in terms of compressive strength (CS) and CO_2eq emission (CE). The first step focused on optimizing the formulation of low-carbon pozzolanic binder of TIM, composed of aerial lime (AL), calcined clay (CC) and calcium-based activator (CBA) with mixture design. The second step targeted to lower the environmental impact by reducing TIM paste content by improving early strength development through pozzolanic activators (PA). The impact of these activators on the hydration kinetics was investigated through CS tests and isothermal calorimetry tests. Results from the mixture design show that optimized binder present a 74% increased CS28d compared to the initial binder, while maintaining same constituents. Furthermore, adding 10% sulfate-based activator (SBA) increased the CS7d of the CBA-free optimized binder by 17% compared to the optimized CBA-containing binder, while reducing CE by 32%.

Keywords: Thermal insulation mortar (TIM); Low-Carbon Binder; Mixture design; Pozzolanic activator.

See Full Paper in the Proceedings.

Development of Advanced Cementitious Composites using the Pre-Placed Macro-Encapsulation Aggregate Method for Thermal Energy Storage Systems

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Abstract. This study investigates the development and performance of a Thermal Energy Storage system employing cement-based encapsulated phase change materials (PCMs) enhanced by expanded perlite aggregates. The pre-placed aggregates method is used by making self-leveling High-Performance Mortar (SLM) to integrate aggregates and cementitious matrix. Utilizing the pre-place aggregate method, PCM-enhanced perlite aggregates were encapsulated through a cementitious process and mixed into SLM to form a consistent TES mortar. The research focuses on optimizing building energy efficiency while maintaining human thermal comfort. Mechanical and rheological properties of the SLM were evaluated, alongside thermal performance assessments. Results demonstrate that the PCM-enhanced SLM mortar, combined with perlite, significantly improves thermal regulation and energy storage capacity, offering a promising solution for sustainable building materials with enhanced thermal comfort.

Keywords: Self-leveling cementitious mortars (SLMs); Pre-Placed Aggregate Method; Bio-based Phase Change Materials (PCMs); expanded perlite (EP); Thermal Energy Storage (TES); Thermal Conductivity.

See full paper in the proceedings.

Tests on cores to determine compressive properties of existing masonry: influence of cap material and geometry

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Abstract. Evaluating mechanical properties of existing constructions represents a challenging task, especially when dealing with historical masonry buildings, on which diagnostic investigations should be as less invasive as possible. In the last decades, the possibility of testing masonry cores to derive compressive and shear properties has been investigated, showing promising results, supporting the diffusion of this testing technique. However, there are still no specific guidelines that define standard procedures for the application of these testing methodologies. In more detail, with reference to compression tests on cores, they can be performed considering several core geometries and bond patterns and adopting different setups. To be tested in compression, cores should be capped with a high-strength material, with the objective of simulating the confinement given by the masonry on-site and providing regular surfaces on which the compressive load can be applied. In literature, different characteristics of the cap, in terms of material and geometry, have been considered, but the study of the correlation between cap properties and core test results is still a matter of debate. For this reason, in this work, compression tests on masonry cores are carried out with the aim of evaluating the influence of the cap material and geometry on the test results, so to assess the reliability of the compression test on cores in estimating the compressive strength of masonry. Single-wythe cores, having a diameter of 100 mm and two different bond patterns (with a horizontal mortar joint or with a horizontal and a vertical mortar joint), are tested, considering a steel or a high-strength mortar cap and different cap geometries, in terms of length and height. The core test results are compared with the results of standard compression tests to evaluate the reliability of the test methodology and identify the parameters which could mostly influence the test outcomes.

Keywords: Masonry, Slightly-destructive test, Core test, Compressive properties, High-strength mortar cap.

See full paper in the proceedings.

ANTIMICROBIAL COATINGS FOR HERITAGE STONES

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Abstract

Natural stones, like marble, limestone and sandstones, which constitute the building material of numerous historic monuments all around the globe, are often affected by biodeterioration, caused by microorganisms such as bacteria, algae, fungi, and lichens. These microorganisms can induce stone deterioration via chemical, physical and mechanical processes. Because of climate change, biodeterioration is predicted to be worsened in the future. To prevent biodeterioration, the use of metal and metal oxide nanoparticles (e.g. Ag, ZnO, CuO, TiO2) with biocidal action has been proposed long ago. However, the available methods of anchoring these nanoparticles onto architectural surfaces lack compatibility and/or durability over time. Therefore, here we propose an innovative method to provide architectural surfaces with antimicrobial ability, by combining metal nanoparticles with phosphate coatings, formed in situ over stones. Thin films of calcium phosphate minerals can be formed via wet chemistry over the surface of heritage stones to protect them from dissolution in rain and inside the pores and intergranular fissures to improve the stone mechanical properties. In the present study, we investigated different methods to functionalize calcium phosphate coatings formed on marble, limestone and sandstones with biocidal nanoparticles. The antimicrobial action was assessed by quantifying the number of colony forming units (CFU) of environmental bacterial strains on treated stone samples, in comparison with untreated references. The resistance of the antimicrobial coatings to nanoparticle leaching in rain was assessed by subjecting functionalized samples to accelerated ageing by a simulated rain. Finally, the colour change induced by the treatments was assessed right after the treatment application and over time, to ensure the treatment compatibility. The results of the study show that, depending on the type of substrate (differing in terms of mineralogical composition, pore system and colour), coating functionalization by different types of nanoparticle can provide durable antimicrobial action, with limited colour change.

Keywords: Marble, Limestone, Biodeterioration, Bacteria, Nanoparticles, Calcium phosphate



INFRASTRUCTURE:
structural behaviour
robustness
assessment
repair

Large-scale Performance Evaluation of Permeable Concrete Pavement

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Abstract. The increasing extent of impervious urban surfaces has intensified challenges such as surface runoff and urban heat island phenomenon. Permeable concrete pavement (PCP) offers a sustainable solution by facilitating water infiltration. This study presents a large-scale evaluation of a laboratory-optimised mixture design (Opt. mix), which was developed to make a balance between strength and permeability, in comparison with a commercial reference mixture design (Ref. mix). A field trial was conducted at a car park in Melbourne, Australia, comprising two adjacent parking bays, one paved with Opt. mix and the other with Ref. mix. During paving bays with the mixture designs, samples were collected from fresh permeable concrete to conduct a comprehensive series of tests. Laboratory tests were performed on field samples to assess compressive strength, flexural strength, indirect tensile (IDT) strength, and permeability. In addition, in-situ double-ring infiltration rate (DRIR) test was carried out at planned time intervals to monitor the variation of infiltration rate over time.

According to the experimental results, Opt. mix exhibited up to 34% higher compressive strength, approximately double the IDT strength, and up to 65% higher flexural strength compared with Ref. mix. In addition, Opt. mix also demonstrated slightly higher permeability, 0.95 cm/s, than the Ref. mix, 0.8 cm/s. The results of DRIR test indicated a gradual decline in infiltration rate over four months for both pavements, with a more pronounced reduction in Opt. mix, likely due to larger aggregate size and higher clogging susceptibility. Overall, this study provides large-scale empirical evidence on the mechanical and hydrological performance of PCP constructed with Australian materials. The findings highlight the potential of optimising permeable concrete mixture design and show performance advantages over commercially used mixtures. Moreover, the infiltration monitoring results provide valuable insights into clogging of PCP under real field conditions and its influence on its service life.

Keywords: Permeable Concrete Pavement (PCP), Pervious Concrete Pavement (PCP), Field Trial, Mechanical and Hydrological Performances, Strength and permeability, Compressive Strength.

See Full Paper in the Proceedings

Structural performance of 3D-printed concrete beams with CFRP reinforcement: a parametric investigation of shear behavior

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Abstract. This study presents an experimental investigation into the shear strength of 3D-printed concrete (3DPC) beams subjected to three-point bending. The campaign focused on evaluating the influence of various parameters, including longitudinal reinforcement ratio, beam height, shear slenderness, as well as the effect of a deliberate pause during the printing process. To assess the specific behavior of 3DPC, a reference beam was traditionally cast for comparison. All specimens were reinforced longitudinally with carbon fiber reinforced polymer (CFRP) rebars. The primary objectives were twofold: to compare the structural performance of 3D-printed versus cast beams, and to examine the sensitivity of printed beams to variations in geometric, printing and mechanical parameters with regard to shear strength. Results highlight differences in bond behavior between printed and cast specimens, which in turn influence the failure mechanisms and overall shear capacity. Notably, a 15-minute interruption in the printing process was found to not diminish beam capacity, but a 60-minute gap did affect interlayer bonding, resulting in an altered crack pattern and earlier failure. The findings of this study contribute to the broader advancement of innovative construction methods by deepening the understanding of 3DPC's structural behavior and its interaction with CFRP reinforcement. Ultimately, the results reinforce the potential of 3D printing as a viable technique for the development of resource-efficient, load-bearing concrete structures.

Keywords: 3D-printed concrete, shear behavior, CFRP reinforcement, printing interruption, parametric investigation, additive manufacturing.

See Full Paper in the Proceedings

Quantifying the impact of artificial surface roughness on the bond performance of commercial repair mortars

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Abstract. The interfacial bond between repair mortars and concrete is often considered the weak link in concrete repair. Achieving material performance compatibility and interfacial bonding is essential to ensure a monolithic behaviour of the repaired structure. Vital to this is adequate surface preparation particularly by, among others, surface roughening. However, conventional concrete removal techniques produce large roughness variations within a single repair zone, complicating objective comparison between various repair mortars and bond strengths. Therefore, this research proposes a reproducible methodology to create a controlled concrete surface roughness, which is then validated against an on-site removal method. In this respect, four artificial roughness types are mathematically designed and applied to a fresh poured MC(0.4) and C(0.4) concrete with three consisting of varying groove configurations and one consisting of localised round chipping. Their roughness was quantified using mathematical calculations, the sand patch test and 3D scanning software. Afterwards, four commercial repair mortars were applied to the prepared substrates, resulting in 16 test combinations. Bond strength is determined using the standardised pull-off and slant-shear tests, while internal bond quality is assessed via Ultrasonic Pulse Velocity (UPV) measurements. From these tests, it was found that 3D scanning provided the most accurate assessment, although slight overestimations occurred due to edge effects. The sand patch method illustrated some usage limitations for very rough and inclined surfaces. Slant-shear tests demonstrated that rougher surfaces with a favourable groove orientation enhanced mechanical interlocking, resulting in enhanced bond strength. Pull-off tests consistently reveal interfacial failure, with no correlation to surface roughness. UPV measurements correlated with pull-off strength, with lower pulse velocities associated with lower bond quality.

Keywords: Repair mortar, Roughness, Bond strength, Non-destructive test

See Full Paper in the Proceedings.

ORIGAMI-REINFORCED CEMENTITIOUS COMPOSITES

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Abstract

Origami-inspired structures with negative Poisson's ratio (NPR) offer unique advantages for reinforcing cementitious materials. This research proposes Origami-Inspired Concrete-Filled Columns (OCFCs), a novel class of architected composites with enhanced strength and ductility. An OCFC consists of an origami-inspired shell, serving as permanent formwork, and an infilled concrete core. Unlike conventional concrete-filled steel tubes (Fig. 1a) or fiber-reinforced polymer (FRP)-confined columns, where the outer shell reacts passively to lateral expansion (damage) of the concrete core, the thin-walled origami-inspired shells proposed in this research offer a fundamentally different pathway: active confinement of the concrete core driven by the intrinsic folding mechanics of the origami geometry (Fig. 1b), independent of concrete bulging and damage state. Under axial compression, the origami-inspired shells fold inward laterally (Fig. 1c) and generate inward restraining forces on the core. This folding mechanism provides active, geometry-driven confinement to concrete and enhances strength, ductility, and energy absorption of the composite structure.

To validate the proposed structure, this study transforms NPR origami patterns (e.g., the waterbomb) into cylindrical shells using parametric design tools and fabricates them via additive manufacturing, followed by evaluation of their deformation behavior and NPR effects. The printed shells serve as formworks for casting mortar, which is subsequently cured and tested together as OCFC composites. The OCFC prototypes are subjected to uniaxial compressive testing to quantify strength and ductility enhancements and to elucidate the underlying synergy between the shell and the cementitious core. Furthermore, advanced characterization techniques, such as in-situ and ex-situ X-ray computed tomography, are employed to capture damage evolution and interaction mechanisms. This work presents a novel reinforcement strategy by integrating architected materials into cement-based systems, offering a new direction for developing high-performance and resilient structures.

Keywords: Origami; Architected structure; Additive manufacturing; Cementitious composites; Ductility.

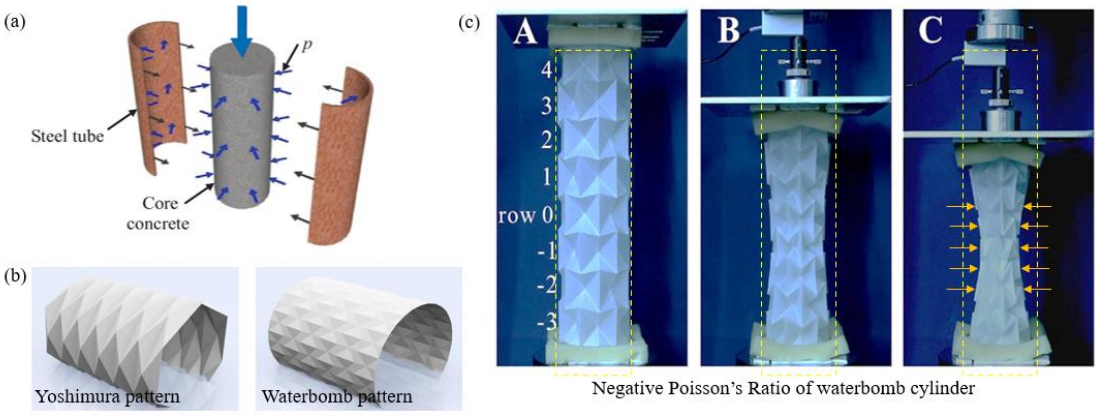


Fig 1. (a) Conventional concrete-filled steel tube configuration [1]; (b) classic origami patterns [2] and (c) NPR behavior (waterbomb) [3].

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DIMENSIONAL ACCURACY OF SPRAYED SHCC LAYERS IN STRUCTURAL RETROFITTING: A PARAMETRIC STUDY

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Abstract

Robotic shotcrete offers enhanced efficiency in high-precision retrofitting applications. However, the sprayed layers often exhibit uneven thickness due to material and process related factors. To achieve the required geometric accuracy, robotic post-processing is essential. This study focuses on the application of robotic micro-power floating as a post-processing technique to ensure the desired geometrical accuracy and to enable seamless integration with the robotic shotcrete system. The shotcrete material used is a strain-hardening cementitious composite (SHCC), selected for its superior performance.

Without proper optimization of the process parameters, robotic post-process can cause fiber pull-out from the sprayed layers, thereby compromising their performance. To address this issue, the study investigates and interrelates two key process parameters – rotational speed and robotic movement speed – with one material parameter, the yield stress required to initiate post-process). The material was first sprayed into formworks and subsequently tested for yield stress at different time intervals after water addition. Robotic micro-power floating trials were then conducted under predefined combinations of material and process parameters.

Preliminary visual observations show that, at an early material age (prior to the initial setting time), a combination of high rotational speed and low robotic movement speed resulted in poor surface quality. In contrast, after the initial setting time, achieving high-quality micro-power floating required a sufficiently high rotational speed paired with a low robotic movement speed. Regardless of the material state, fiber pull-out was mitigated through appropriate optimization of both parameters. Future research will incorporate both 2D and 3D scanning techniques to quantity surface roughness and flatness.

Keywords: SHCC; Strengthening; Robotic shotcrete; Robotic post-processing; Surface quality.

A Thermo-Mechanical Model for Assessing Early-Age Thermal Cracking in Mass Concrete

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Abstract. Thermal cracking is a major concern in mass concrete structures due to excessive temperature differentials between the core and the surface, which can significantly affect durability and long-term performance. This study develops a degree-of-hydration-based thermo-mechanical model to simulate early-age thermal cracking in concrete. Unlike conventional approaches that use the maturity method to account for time and temperature dependence of mechanical properties, the proposed model expresses the degree of hydration as a function of time and temperature using a second-order polynomial Bernhardt function. Mechanical properties such as compressive strength, Young's modulus, tensile strength, and fracture energy were determined at different ages and correlated with the degree of hydration obtained through nonlinear regression to capture the age-dependent strength development. The model was implemented in COMSOL Multiphysics® by coupling heat transfer and structural mechanics modules, where temperature distributions in a slab measuring 22.8 m × 8.55 m × 1.5 m were computed from the transient heat transfer equation and applied as thermal loads in the structural analysis to evaluate stress and cracking behavior. This study demonstrates how the proposed thermo-mechanical model can be calibrated using experimental data and applied to simulate early-age thermal cracking in real structures, thereby providing a valuable tool for understanding thermal stress development and devising preventive measures in mass concrete applications.

Keywords: Mass concreting, cement hydration, degree of hydration, thermo-mechanical modelling.

See full paper in the proceedings.

Optimizing flexural performance of slender reinforced concrete beams with different combinations of GFRP and fabric or grid reinforcement: An experimental study

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Abstract: Corrosion of steel reinforcement is one of the main degradation mechanisms in reinforced concrete structures, negatively affecting their durability and performance. In this context, non-metallic reinforcements, especially those made of fiber-reinforced polymers (FRP), have emerged as a viable solution, offering high corrosion resistance, low weight, and a good strength-to-weight ratio. Despite some limitations in structural detailing—such as the inability to bend after fabrication, lack of yield capacity and the brittle failure. —FRP allows the design of lighter and more durable elements, with lower maintenance demands. Recent studies highlight the potential mechanical performance of FRP-reinforced concrete, including the use of bars combined with open-mesh fabrics or grid in optimized sections, where in this study specifically, they will be adopted especially as stirrups with the main purpose of allowing greater deformations and avoiding premature failures in the concrete. Considering the advances in research, the development and implementation of these technologies represent a promising path towards more efficient and sustainable structures in civil engineering. Therefore, this study aims to analyze the best configuration of hybrid reinforcements, i.e., the combination of Glass-FRP bars and fabrics or grid, in I-section beams, with a single geometry and reinforcement ratio, aiming at the reduction and optimization of the section and material consumption through the experimental analysis of the bending behavior of the beams, contributing to the sector's technical and sustainable advancement.

Keywords: Non-Metallic Reinforcement, Textile-Reinforced Concrete (TRC), I-beam, High-Performance Concrete (HPC)

See full Paper in the Proceedings

PUSH-OUT TESTS ON TIMBER-CONCRETE COMPOSITE STRUCTURES REINFORCED WITH NATURAL FIBRES

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Abstract. Over the last few years, natural fibres such as hemp have emerged as promising alternatives to synthetic fibres for textile reinforcements in structural engineering applications. Their eco-friendly trait, economic feasibility and mechanical properties drew attention to the possibility of using them in less conventional applications such as timber-concrete composites. Timber-concrete composites (TCC) are hybrid structures consisting of timber and concrete elements joined together by a shear-resistant joint. This construction method utilises the strengths of both materials and offers advantages in load-bearing capacity. To assess whether a reliable connection between timber and concrete can be achieved without anchorage devices, push-out tests were conducted on concrete specimens reinforced with multilayer textiles of natural fibres. The textiles were placed in configurations ranging from one to four layers. The results showed that most specimens failed at lower loads than theoretically predicted. A key observation was the formation of a small compression strut angle caused by the absence of anchorage, which reduced the shear capacity of the concrete and governed the failure mechanism. Specimens with one or two layers of reinforcement primarily failed in bending, indicating limited flexural capacity. In contrast, those with three or four layers reached maximum loads comparable to steel-reinforced reference specimens, with failure occurring by concrete notch shearing, timber lamella shearing, or timber compression. These results suggest that increasing the number of textile layers can significantly improve load-bearing capacity. With further refinement of design provisions and consideration of flexural behaviour, textile-reinforced concrete made of natural fibres could contribute meaningfully to more sustainable building solutions.

Keywords: Timber-concrete composites, Textile reinforced concrete, Natural fi-bres, Push-out tests, Design provisions.Keywords: Timber-concrete composites,Textile reinforced concrete, Natural fi-bres, Push-out tests, Design provisions.

See full Paper in Proceeings

BENDING BEHAVIOR OF TIMBER-CONCRETE COMPOSITE STRUCTURES REINFORCED WITH NATURAL FIBERS

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Abstract. Growing environmental concerns and the pursuit of sustainable construction materials have motivated the use of natural fibre reinforcements as alternatives to synthetic ones. However, their application in timber–concrete composite (TCC) beams has not been widely explored. This study investigates the bending behaviour of TCC beams reinforced with multilayer textiles made of natural fibres through four-point bending tests. Four identical beams, each with textile reinforcement embedded in the concrete slab and notched connections for shear transfer, were tested. Unlike conventional practice, no uplift protection devices were employed. The underlying hypothesis was that the unconventional textile reinforcement would provide sufficient bending capacity to counterbalance uplift moments, potentially eliminating costly and labour-intensive uplift protection.

Experimental results showed that shear failure in the notches occurred prematurely, preventing the reinforced slabs from fully mobilising their intended bending capacity. Nonetheless, the beams consistently met the shear capacity of the notches, demonstrating safe load-bearing performance even without uplift protection. The results were compared against preliminary push-out tests and reference values from CEN/TS 19103 design models. Despite the absence of significant gains in bending capacity, reinforcement remained essential to transfer eccentric moments and tensile forces in the notch regions, which are not accounted for in concrete tensile strength per EN 1992-1-1.

The four-point bending tests revealed load-bearing capacities comparable to reference values, confirming that notched connections performed reliably despite the lack of uplift protection. However, variability in notch stiffness was observed,

largely attributable to inconsistencies in lamination and concrete compaction. These led to voids and reduced shear performance, highlighting the importance of precise manufacturing for uniform concrete placement.

The findings emphasise both the potential and the limitations of natural fibre textile reinforcements in TCC systems. Recommendations for improved production methods are provided to enhance future applications in timber–concrete slab systems.

Keywords: Timber-concrete composites, Textile reinforced concrete, Natural fibres, Four-point bending tests.

See Full Paper in Proceedings

MULTI-ION INDUCED REACTIVE CORROSION IN MARINE REINFORCED CONCRETE: A COUPLED CHLORIDE-SULPHATE-CARBON DIOXIDE INTERACTION FOR ENHANCING SERVICE LIFE ASSESSMENT

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Abstract

Reinforced Concrete (RC) piles form part of critical coastal infrastructure, but their durability is severely challenged by multi-ion interactions occurring under harsh marine exposure. Traditional service-life models typically consider chloride ingress alone, neglecting the coupled effects of sulphate attack and atmospheric carbonation (CO_2), which jointly alter concrete microstructure and influencing reinforcement corrosion. This study introduces a Multi-ion Reactive Corrosion (MiRC) model—a depth-dependent, fully coupled model that integrates chloride, sulphate, and CO_2 transport reaction processes with evolving material properties: chloride binding (forming Friedel's salt), sulphate reactions (forming gypsum/ettringite), and CO_2 carbonation (forming calcite) all dynamically change pore structure. The model captures both protective (pore-filling) and detrimental (cracking-induced) mechanisms governing the transition from surface salt leaching, densification to internal degradation.

Results are presented through normalized diffusion coefficients (D/D_o), normalized concentration and porosity profiles (C/C_s, ϕ/ϕ_o), corrosion initiation and service-life timelines. Parametric analyses show that reducing initial porosity and adopting sulphate-resistant binders can delay corrosion by up to 80%, while the sulphate-to-chloride ratio critically determines whether sulphate retards or accelerates chloride ingress. The framework further accounts for carbonation-induced pH reduction, which lowers the chloride threshold for steel depassivation and destabilizes bound chlorides.

By linking chemical deterioration with structural implications, the MiRC framework supports predictive maintenance and resilience planning for marine infrastructure. It enables early identification of deterioration-prone zones—especially in splash and tidal regions—and informs repair strategies under evolving climatic conditions, including increased atmospheric CO_2, location-specific surface exposure to aggressive agents. Overall, this research advances RILEM's mission of developing sustainable and durable concrete systems through mechanistic understanding of multi-ion corrosion and its coupled effects on material and structural performance.

Keywords: Marine reinforced concrete; multi-ion corrosion; Chloride ingress; Sulphate attack; Carbonation; Service life modelling

EVALUATION OF THE TENSILE PERFORMANCE OF CALCIUM HYDROXIDE ACTIVATED ULTRA-HIGH-PERFORMANCE FIBER-REINFORCED SLAG COMPOSITES

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Abstract

Alkali-activated slag composites (AASCs) have attracted considerable attention due to their lower carbon emissions compared with conventional cement-based materials. However, their practical application is hindered by issues such as rapid setting, the need for pre-preparation of activators, and extremely high pH. These challenges become more pronounced when developing high-performance materials. To address these problems, this study employed calcium hydroxide (CH), which has relatively low solubility, as an alkali activator to mitigate the drawbacks of conventional high-performance alkali-activated slag composites, in particular rapid setting, pre-preparation of activators, and excessively high pH. Isothermal calorimetry tests were conducted to examine the early hydration behavior, and X-ray diffraction (XRD) analysis was performed to identify the reaction products. The tensile performance of CH-activated high-performance slag composites was evaluated through direct tensile tests. As the dosage of the alkali activator increased, the pH of the mixture rose, leading to accelerated slag activation. Consequently, the heat released during the reaction increased, and the setting time shortened. The XRD results indicated that at a CH content of 7.5%, the peak intensity of C–S–H(I), known for its dense microstructure, reached its maximum. Beyond this dosage, the formation of dense C–S–H(I) did not further increase, while the formation of less dense C–S–H decreased. Therefore, the tensile strength, strain capacity, and energy dissipation achieved optimal values of 18.6 MPa, 0.74%, and 113.5 kJ/m^3 at 7.5% CH content. When the CH dosage exceeded 7.5%, tensile strength gradually decreased due to reduced formation of less dense C–S–H; however, the strain slightly increased to 0.77%, exhibiting the highest deformability but a lower energy dissipation of 91.7 kJ/m^3 compared with CH7.5.

Keywords: Ultra-high-performance alkali-activated slag composites, calcium hydroxide, tensile performance



TEXTILE REINFORCED CONCRETE

INTEGRATION OF PREFABRICATED SHEAR WEBS INTO TEXTILE-REINFORCED CONCRETE I-BEAMS: EXPERIMENTAL STUDY

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Abstract. To reduce the carbon footprint of concrete structures in the built environment, textile-reinforced concrete (TRC) offers a promising solution. TRC uses non-corrosive fibers, such as carbon or glass, instead of traditional steel reinforcement, thereby reducing the required concrete cover and, consequently, the overall concrete volume. With less concrete cover, slender, structurally efficient elements such as I-beams can be manufactured. However, producing such TRC elements is often labor-intensive and requires complex formwork. To address this challenge, this study focuses on integrating prefabricated shear webs to simplify the manufacturing process. Instead of casting all elements in a single cast, they are cast in multiple stages using simpler formworks. The present experimental study compares the behavior of single-cast TRC beams in a 4-point bending test setup with that of TRC beams manufactured using prefabricated shear webs. The latter are tested both with and without galvanized steel pins at the web-to-flange interface to enhance dry connections. The results of the test showed that the precast shear webs I-beams have a slightly lower stiffness and ultimate strength than single cast beams, reaching 95% and 89% of the single cast element's ultimate failure load for the case with and without pins, respectively. All specimens tested failed by web shear when the diagonal compression strut between cracks crushed.

Keywords: Textile-Reinforced Concrete (TRC), I-beams, prefabricated webs, carbon textiles.

See Full Paper in the Proceedings

TEXTILE-REINFORCED AEROGEL-INCORPORATED CEMENTITIOUS COMPOSITES; PART A: INVESTIGATIONS ON THE MATRIX AND ANALYTICAL PREDICTION OF THE COMPOSITE BEHAVIOUR IN BENDING

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Abstract

The reinforcement of cementitious mortars by structural textiles has emerged in the past few decades as means of manufacturing thin, lightweight and slender elements that contribute to lowering the overall production of concrete. In addition, the incorporation of aerogel particles into cementitious mortars recently gained the attention of the scientific community as a promising method to produce lightweight mortars with insulating capacities that exceed the current limits of aerated concrete, owing to the extremely low thermal conductivity of aerogels. The combination of the above offers the potential to produce thin, ultra-lightweight, insulating structural concrete members. However, the presence of aerogels hinders the mechanical properties of the mortar; thus, the factors that determine the trade-off between gain in insulation capacity and loss in mechanical properties need to be identified and quantified.

This study focuses on the effect of the aerogel particles on the elastic and thermal properties of the mortar. This is done by a microscopy analysis on aerogel-incorporating mortar samples (namely 'aerocement') that identifies the particle size distribution in the matrix. Mechanical tests are then conducted to determine the strength and Young's modulus of the aerocement. Finally, thermal conductivity measurements are conducted and the results of all properties are correlated. Since the goal is the production of textile-reinforced aerocements, the next step performed in this study is an attempt to predict the flexural capacity of thin aerocement elements reinforced with glass and basalt textiles. The prediction is based on a cross-section analysis using a fiber model that takes into account the properties of the mortar that were determined experimentally and the properties of commercially available textiles, assuming a purely flexural behaviour and a perfect bond between the two components. The analytical results are compared to experimental ones which are discussed in more detail in the second part of this study.

Keywords: aerated concrete, aerogel, cement composites, textile reinforced concrete, textile reinforced mortars

Textile-reinforced aerogel-incorporated cementitious composites; part B: Thermomechanical characterization of the matrix and the flexural composite behavior

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Abstract. This study explores the incorporation of silica aerogel particles in a cementitious mortar applied as the matrix of Textile Reinforced Cement (TRC) composites, using three-dimensional glass textiles. The work focuses first on the mechanical and thermal characterization of the mortar followed by the assessment of the flexural composite behavior of the TRC specimens, in ambient and elevated temperatures (200 °C and 300 °C). The temperature effect on the mortar's compressive strength is limited, whereas its flexural tensile strength and the TRC flexural composite behavior are strongly affected by heat-related deterioration. All results on the mortar and the TRC composite level are compared to their zero aerogel content alternatives. Including lightweight, hydrophobic silica aerogel reduces the mortar's mechanical properties and affects its composite action with the textile reinforcement. However, it substantially decreases density and thermal conductivity, resulting in an innovative, lightweight, insulating structural material with balanced thermomechanical properties.

Keywords: Aerogel Particles, Cement Composites, Lightweight Concrete, Textile Reinforced Cement, Thermomechanical Properties, Elevated Temperature

See Full Paper in the Proceedings

MECHANICAL BEHAVIOUR OF HYBRID TEXTILE REINFORCED CONCRETE

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Abstract. This paper presents an experimental investigation into the uniaxial tensile behaviour of hybrid textile-reinforced concrete (h/FRCM). The study focuses on the synergy between an Alkali-Resistant (AR) glass fabric and four different High Performance Fibre-Reinforced Concrete (HPFRC) matrices, varying by supplier and rheology. An experimental program was conducted, including uniaxial tensile tests on hybrid composites, HPFRC and Textile-Reinforced Concrete (TRC) without steel fibres (SF) to isolate the contribution of each component. The results consistently showed that fabric inclusion transformed the quasi-brittle, strain-softening failure of HPFRC into a quasi-ductile, strain-hardening response with multiple cracking and significant deformation capacity. A synergistic effect between SF and the fabric was observed in the hybrid systems, leading to higher tensile capacity. A clear correlation between the matrix's post-cracking flexural performance and the composite's efficiency was established, highlighting that matrix properties are a key factor for material selection in structural retrofitting.

Keywords: High performance fiber reinforced concrete, fiber reinforced cementitious matrices, FRCM, Hybrid FRCM, material characterization, uniaxial tensile behaviour.

See Full Paper in the Proceedings

Influence of variable stress ratios on carbon-reinforced concrete under biaxial tensile loading

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Abstract. Concrete pavements show damage from traffic loads and water-dissolved pollutants such as chlorides and alkalis at the joints after only a short period of use. To repair concrete pavements and extend their service life, carbon-reinforced concrete (CRC) is suitable as a joint covering layer. In addition to traffic loads, the CRC covering layer is primarily exposed to environmental influences such as temperature changes over time. If the temperature drops from zero into the low temperature range, the joints in the concrete pavement open and the CRC covering layer is subjected to tensile stress. The carbon reinforcement enables the formation of cracks due to tension above the joints with small crack spacing and small crack widths. Biaxial tensile stresses arise above intersecting joints. The stress ratio of the biaxial tensile load in the CRC covering layer varies depending on the spacing of the transverse and longitudinal joints in the concrete pavement. In the present study, the load-bearing and deformation behavior of the CRC covering layer were analyzed, taking into account the influences of different stress ratios. For this purpose, biaxial tensile tests were carried out on slab specimens with a two-layer carbon grid. The results allow for a configuration of the CRC covering layer under consideration of different tensile stress ratios.

Keywords: carbon-reinforced concrete, carbon reinforcement, biaxial tensile load, load-bearing behavior, deformation, crack behavior.

See full paper in the proceedings.

Investigation of Pull-Out and Beam-End Bond Behavior of Non-Metallic Reinforcing Bars in Low-Clinker Concretes

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Abstract. This study investigates the bond behavior of CFRP and GFRP rebars embedded in eco-concrete (EC). Pull-out and beam-end tests were conducted to assess the influence of bond length and concrete cover. Results show that both CFRP and GFRP rebars exhibit reliable bond performance with EC. Differences in stiffness and maximum bond strength were observed between the two reinforcement types, attributed to rebar surface morphology. While CFRP rebars displayed stiffer bond behavior, GFRP rebars achieved higher maximum bond stress values due to their more pronounced surface texture. The study further demonstrates that a reduced concrete cover of 20 mm does not impair bond performance, underscoring the potential for slender and material-efficient components with non-metallic reinforcement.

Keywords: bond test, GFRP, CFRP pull-out test, beam-end test, non-metallic reinforcement

See Full Paper in the Proceedings.

High-temperature-induced concrete spalling

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Abstract. High temperature induces concrete spalling particularly affects concretes wit dense structure, such as those used for carbon-reinforced concrete (CRC). However, a high fire resistance class is essential for the widespread practical application of CRC. In addition to the importance of the material properties of the components concrete and reinforcement, the test methods used to determine these properties are also of particular importance. Fire tests using the standard temperature-time curve according to DIN EN 1363-1:2012-10 are complex and therefore unsuitable for the initial characterization of new materials or minor modifications. A simplified PTM (pressure, temperature, mass) test setup to investigate high-temperature-induced spalling of high-performance concrete, used for carbon-reinforced concrete is presented here. The functionality of the test setup was tested using a High-Performance Concrete (HPC) specially developed for the production of carbon reinforced concrete structures. By adding short polypropylene (PP) fibers, concrete spalling was completely prevented, and the processability required for the production of CRC using the lamination process was maintained through minor modifications to the concrete composition.

Keywords: Concrete spalling, Carbon-reinforced concrete; HPC, Temperature, Polypropylene

See Full Paper in the Proceedings.

TEXTILE-REINFORCED MORTARS: CAN THEY BE SMART-IFIED?

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Abstract

Textile-Reinforced Mortars are well established as highly suitable retrofitting solutions for heritage structures, owing to their high compatibility with a variety of historic substrates while preserving aesthetics. However, mortar cracking may compromise their long-term performance, and potentially result in further repairs and costs. To address this, integrating smart technologies to transform existing TRM into multi-functional systems is emerging as a key advancement and will enable a much needed shift from corrective to re-active retrofitting.

This paper examines separately the self-healing and self-sensing functionalisation of Textile-Reinforced Mortars, comprising an alkali-resistant glass textile embedded into a lime-based mortar. Crystalline admixtures and recycled carbon fibres were incorporated in the mortar to impart self-healing and self-sensing functionalities, respectively. The self-healing performance was assessed on pre-cracked TRM composite prisms (160 x 40 x 40 mm) after one month of healing through capillary absorption and mechanical tests and detailed microscopic analyses. The self-sensing performance was assessed on TRM coupons (500 x 50 x 10 mm) subjected to direct tension by concurrently monitoring the change in their electrical resistance under DC injection and under monotonic loading up to rupture.

The preliminary results highlight the tremendous potential of lime-based Glass-TRM systems in achieving excellent self-monitoring and damage-sensing capabilities, with inherent self-healing of cracks up to 0.15 mm.

Keywords: smart, TRM, self-sensing, self-healing, crystalline admixtures, piezoresistivity

STRUCTURAL PERFORMANCE OF TRC-STRENGTHENED CONCRETE SPECIMENS UNDER IMPACT LOADING

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Abstract. Reinforced concrete (RC) structures under impact loading may suffer severe damage such as scabbing, spalling, or perforation. Retrofitted thin layers of mineral-bonded composites offer a material-efficient strengthening option.

In this study, impact experiments were carried out on 10 cm and 20 cm thick RC plates at the TU Dresden drop tower facility. Six specimens were tested, including reference plates and variants retrofitted with 2 cm layers of textile-reinforced concrete (TRC) or strain-hardening cementitious composites (SHCC) applied to the rear or front-side.

TRC layers most effectively retained fragments and reduced scabbing even at higher velocities. Rear-side SHCC could better distribute local strains, preventing visible cracking, while front-side SHCC improved penetration resistance. These findings demonstrate that thin retrofitted layers can enhance impact resistance of RC plates while remaining material efficient.

Keywords: Impact loading, reinforced concrete, drop tower, TRC, strengthening layer, damping layer.

See Full Paper in the Proceedings.

Influence of Impregnation Systems on the Structural Behavior of Carbon TRC I-Section Beams: Experimental Study

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Abstract. The application of Textile Reinforced Concrete (TRC) in the manufacturing of new structural elements has attracted considerable attention over the last decade. While carbon textiles exhibit high mechanical properties, these fibers present low bond with concrete due to their multifilamentary nature and hydrophobic surface. This inherent poor bond compromises the structural performance of TRC. The polymeric impregnation of the textiles has been widely employed to address such issues. Nevertheless, the resulting behavior varies significantly depending on the type of impregnation material. This study investigates the structural behavior of carbon TRC I-section beams with water-based epoxy (WBEP) and thermoplastic resin (THRM) coatings through four-point bending tests, aiming to contribute to the use of new alternative coatings in the structural application of TRC. The results are compared to a commercial solvent-based epoxy (EPXY)-impregnated textile. The findings show that the level of impregnation of the textiles, web-flange connection, textile orientation, and use of overlaps affect the structural performance of TRC I-section beams. The results indicate that despite a premature failure by shear, the WBEP coating imparted good overall structural behavior compared to the commercially available EPXY-impregnated textile, whereas the beam with the THRM coating presented inferior load-bearing capacity due to insufficient anchorage between the web-flange reinforcements.

Keywords: Textile reinforced concrete, carbon textiles, structural performance, waterborne epoxy, thermoplastic resin.

See full paper in the proceedings.

Design Framework for Sustainable Textile-Reinforced Concrete Using Laminate Theory and Damage Modeling

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Abstract Non-metallic textile reinforcement systems incorporating basalt, alkali-resistant (AR) glass, carbon, or natural fibers have emerged as promising alternatives to traditional steel-reinforced concrete. These materials enable the development of lightweight, corrosion-resistant, and durable structures while offering a sustainability solution for the construction industry. This paper introduces a comprehensive analysis model to predict the uniaxial, biaxial, and flexural response of textile reinforced concrete (TRC) sections. The proposed framework employs classical laminate theory to evaluate global stiffness and strength based on the stacking sequence of textile layers, each modeled as an orthotropic lamina under plane-stress conditions. A strain-based damage model is incorporated to simulate matrix stiffness degradation due to progressive cracking, while the Tsai–Wu failure criterion is used to identify failure initiation within individual layers. Global stiffness is updated at each incremental strain step to capture the evolution of damage throughout the section, enabling prediction of the complete load-deflection response.

This analytical framework provides a robust tool for evaluating the structural behavior of TRC sections under combined stress states, particularly in quantifying stiffness degradation as damage accumulates in successive layers. The proposed methodology contributes to advancing sustainable design strategies for cementitious composites in both structural applications and retrofitting scenarios.

Keywords: Textile Reinforced Concrete, Laminate Theory, Damage Modeling, Load-Deflection.

See full paper in the proceedings.

INFLUENCE OF SINGLE AND HYBRID SHORT FIBRES ON THE FRESH AND HARDENED PROPERTIES OF QUATERNARY BLEND CONCRETE FOR SUSTAINABLE TEXTILE-REINFORCED COMPOSITES

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Abstract. This study investigates the impact of various short fibre types on both the fresh and hardened properties of quaternary blend concrete mixes formulated for sustainable and high-performance textile-reinforced concrete (TRC) applications. A total of twenty-nine concrete mixes were developed using quaternary binder blends composed of Portland cement, fly ash, silica fume, and limestone powder, with the binder replacing 70% of the cement by weight and were prepared both without fibres and with short fibres added either individually, alkali-resistant glass, polyvinyl alcohol, or polypropylene, at a volume fraction of 2%, or in hybrid combinations involving two different fibre types maintaining a total fibre volume of 2%. The incorporation of short fibres resulted in a considerable reduction in workability, up to 55%, with the degree of reduction closely linked to the fibre's specific surface area (PP > PVA > ARG). Although the overall compressive strength experienced only slight decreases, certain fibre and binder combinations showed more pronounced reductions. Notably, drying shrinkage was substantially decreased in mixes reinforced with ARG fibres, followed by those with PVA and PP, illustrating the influence of fibre stiffness on shrinkage mitigation. Furthermore, hybrid fibre combinations exhibited additional effects on workability, compressive strength, and shrinkage, where increasing the proportion of lower-modulus fibres such as PVA and PP led to higher drying shrinkage and a decline in fresh concrete performance.

Keywords: Textile-Reinforced Concrete (TRC), Quaternary Blend Concrete, Short Fibres.

See Full Paper in the Proceedings

THE ROLE OF SILICA SOL FIBER COATING IN ENHANCING TEXTILE-REINFORCED CONCRETE PERFORMANCE

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Abstract

Textile Reinforced Concrete (TRC) has emerged as an innovative construction material, offering superior mechanical properties and durability compared to conventional reinforced concrete. The performance of TRC, however, heavily depends on the bond between the textile reinforcement and the cementitious matrix, which plays a crucial role in determining the composite's overall mechanical behaviour. One promising approach to improve this bond is the incorporation of silica particles into the textile reinforcement. This study investigates the enhancement of bonding strength in TRC by coating hydrophilic glass fibers (GF) and hydrophobic aramid fibers (AF) with different types of silica sol: commercially available colloidal silica and a sol synthesized via the sol-gel process. Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) were employed to evaluate the effectiveness of the fiber coating. Pull-out tests were conducted to evaluate the interfacial properties of the silica-impregnated fiber bundles. Results revealed that silica impregnation significantly improved the bond strength between the cement matrix and the fiber bundles compared to non-coated counterparts. For AF, a surfactant pretreatment was critical to achieving a more uniform silica coating, which further enhanced adhesion. The bonding performance showed remarkable improvements, with a 100% increase in bond strength for GF and an 80% increase for pretreated AF. Across all tested sols, the pull-out mechanism exhibited a telescopic failure behaviour characterized by sleeve-core separation. Importantly, the sleeve-to-core ratio was higher for silica-coated fibers compared to non-coated fibers, leading to a more uniform stress distribution during the pull-out process. These findings offer valuable insights into optimizing TRC technology. The improvement in interface bonding makes TRC a viable and advanced solution for lightweight construction applications, where durability and mechanical efficiency are of paramount importance.

Keywords: Textile-reinforced concrete; Bonding mechanics; Pull-out test; Sol-gel; Surface modification.

TRANSFORMATION OF SINGULAR JOINT DEFORMATIONS INTO MULTIPLE CRACKS IN CARBON REINFORCED CONCRETE PAVEMENTS

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Abstract. The joints in Jointed Plain Concrete Pavements (JPCP) represent the system's primary points of weakness. To prevent ingress of moisture and contaminants, these joints are typically sealed. Conventional sealants exhibit limited durability and must be renewed every few years. In addition, the concrete adjacent to the joints often suffers premature damage under combined environmental and mechanical loading. In this project, we propose and investigate an alternative repair concept by overlaying existing concrete joints with a thin carbon-reinforced concrete (CRC) layer. The CRC overlay accommodates positive joint movements by forming a network of fine multiple cracks within a predefined decoupling zone. The latter implies a bituminous or flexible polymer coating acting as decoupling agent between the CRC-layer and the underlying concrete along a predefined length. It must allow the free deformation of the CRC-layer independently of the concrete substrate, in this way promoting controlled crack development. Beyond this decoupling zone the CRC-layer is bonded to the concrete substrate. To assess the performance of this composite system at a representative scale, we developed an innovative laboratory test setup that allows the experimental simulation of both positive and negative joint displacements on large-scale joint elements. The setup is instrumented to monitor crack width, crack spacing and the load displacement-history. In a comprehensive parameter study, we investigate the behavior of the joint system with various overlay configurations in terms of length of the decoupling zone and materials used as decoupling agents.

Keywords: concrete pavements; carbon reinforced concrete; ductile joint overlay

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Numerical Modelling of TRC Shell Formworks: From Homogenized Approaches to Explicit Textile Simulation

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Abstract. This paper presents a numerical investigation of the structural behavior of stay-in-place textile-reinforced concrete (TRC) formworks used in a novel semi-prefabricated slab system. These formworks, designed to reduce self-weight and facilitate on-site assembly, are characterized by a thin-walled geometry reinforced with AR-glass fabrics and are subjected to critical loading during transient construction phases. The study focuses on the simulation of meso-scale material tests and full-scale experiments conducted under a centered point load, representative of a scenario such as the passage of operators during assembly. Three modelling strategies are adopted: a smeared shell approach, a discrete model with explicit representation of the textile reinforcement, and a composite layup approach. All models are implemented in a nonlinear finite element framework, including tensile cracking and the full trilinear behavior of the TRC material. The aim is to explore how textile orientation and positioning within the shell thickness affect the global response, crack development, and ultimate capacity of the formworks. The comparison between the three modelling strategies is intended to assess the ability of each approach to capture global stiffness, collapse mechanisms, and local effects such as crack localization and textile rupture. The outcomes of this study point to the potential and current limitations of numerical modelling strategies in predicting the response of TRC elements under realistic load conditions. These findings open the way for future optimization of reinforcement layout and thickness distribution, with the broader goal of improving mechanical performance while maintaining lightweight construction.

Keywords: Textile Reinforced Concrete (TRC), Numerical Modelling, Nonlinear Analysis, Lightweight Construction, Shell Structures.

See Full Paper in the Proceedings.

Flexural response of fire-damaged beams strengthened with C-FRCM

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Abstract. Reinforced concrete (RC) beams experience significant strength degradation when exposed to fire, especially those reinforced with fiber-reinforced polymer (FRP) bars, which are highly vulnerable to thermal damage. This study experimentally investigates the flexural performance of full-scale fire-damaged concrete beams reinforced with glass FRP (GFRP) bars and retrofitted using carbon fiber-reinforced cementitious matrix (C-FRCM) U-wraps. A beam was exposed to fire in accordance with ASTM E119 for a duration of three hours. Following fire exposure, the beam was strengthened with a single layer of C-FRCM U-wrap and tested under four-point bending. A second beam, which was neither exposed to fire nor strengthened with C-FRCM, served as the control specimen. Both test specimens had uniform dimensions of 300 mm in width, 400 mm in depth, and 5000 mm in length. The test results showed that the strengthened fire-exposed beam gained only 40% of its flexural capacity compared to the control beam. These findings demonstrate that the effectiveness of C-FRCM retrofitting in fire-damaged GFRP-reinforced concrete beams strongly depends on the level of thermal degradation sustained by the internal reinforcement. While the C-FRCM system can partially restore flexural capacity, adequate fire protection is essential to achieve full performance recovery.

Keywords: Strengthening, FRCM, Fire, Damage, Concrete Beam.

See Full Paper in the Proceedings.

Development of Calcined Clay-based Textile Reinforced Concrete

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Abstract. Textile Reinforced Concrete (TRC) is an innovative material in modern construction, combining textile fibers with a fine-grained concrete matrix to create lightweight, thin, and durable composites. TRC offers a sustainable, high-performance alternative to traditional reinforcement systems, with key benefits including reduced material consumption, improved durability, and greater design flexibility. As the construction industry moves toward more resource-efficient and environmentally responsible practices, TRC is receiving growing attention across a wide range of applications.

This research aims to advance TRC technology by incorporating a limestone calcined clay cement-based matrix, reducing dependence on Portland cement and promoting more sustainable binder systems. The composite's structural performance is evaluated through flexural bending tests compared with equivalent TRC composites produced using Portland cement-based matrix at different strength classes.

By integrating low-carbon binder technologies, this study contributes to the development of next-generation TRC systems that align with sustainability targets while producing comparable mechanical performance of conventional binder systems.

Keywords: Textile Reinforced Concrete (TRC), TRM, FRCM, Limestone Calcined Clay Cement, Sustainable Construction, Low-Carbon Binder, Flexural Performance

See Full Paper in the Proceedings.

ADVANCING SUSTAINABLE MATERIALS AND PROCESSES FOR CONSTRUCTION WITH SELF-STRESSING TEXTILE REINFORCED CONCRETE

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Abstract

Textile reinforced concrete (TRC) is an innovative composite material that replaces conventional steel reinforcement with textile fibre reinforcements, resulting in thin, lightweight, and cost-effective structural elements. These characteristics make TRC a promising solution for sustainable repair, strengthening, and new construction applications. Recent advancements, such as mechanical prestressing, have demonstrated significant improvements in the mechanical performance of TRC systems. However, the practical implementation of mechanical prestressing in TRC remains challenging due to technical and logistical constraints.

As an alternative, chemical prestressing or self-stressing offers a promising approach by inducing prestress internally through chemical and physical reactions of the matrices, eliminating the need for external prestressing devices. Despite its potential, the application of self-stressing in TRC remains underexplored, with several key research questions still open.

This paper presents a preliminary experimental investigation aimed at developing self-stressing TRC composites and evaluating their performance, including flexural strength and bond behaviour. The study contributes to advancing innovative material and process solutions that align with sustainability objectives by improving structural efficiency and reducing the need for complex prestressing methods. These findings support the broader adoption of sustainable, high-performance, and innovative composites in infrastructure applications.

Keywords: Textile Reinforced Concrete (TRC), Self-Stressing TRC, Innovative Composites, Flexural Strength, Bond Behaviour, Sustainable Material

Carbon-textile reinforced concrete for modular, origami-based construction system: analysis of stress-redistribution behavior

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Abstract. The malleability of concrete in combination with the foldability of textile reinforcement introduces a vast geometric design space for carbon-reinforced concrete systems. Particularly suitable for structural applications is the waterbomb origami tessellation which enables an integrated design approach synergizing the material and form to achieve high material utilization and structural performance. This facilitates the development of carbon-reinforced concrete (CRC) waterbomb modules that are both lightweight and material-efficient. Leveraging the inherent symmetry and tessellation compatibility of the waterbomb geometry, these modules can be assembled into floor and wall systems through a combination of topological interlocking and bolted connections, ensuring structural continuity, efficient stress transfer, and demountability for reuse.

Designing waterbomb assemblies is challenging due to their geometric complexity, the multitude of interacting components, and the highly nonlinear structural behavior. To overcome these difficulties in an initial design step, the assembly is first decomposed into its constituting units, the waterbomb modules. On this basis, a finite element modeling approach is proposed in which the concrete and the textile-reinforcement are modeled explicitly in a resolved manner. This approach enables us to reliably capture the stress redistribution process and failure modes at the module level. Thus, this approach reduces both modeling complexity and computational cost. This framework provides the foundation for the systematic design and modeling of modular origami-inspired structural members like slabs or walls, where material and interior form are synergyzed to achieve high-performance of demountable carbon-reinforced concrete assemblies

The analysis presented in the paper will illuminate the correspondence between the material, form, and the resulting quasi-ductile failure process in complex modular structural systems. The results of the studies will support the design of a focused test setup for the validation of the predictions.

Keywords: origami, thin-walled shells, textile-reinforcement, structural analysis, folded-structures

See Full Paper in the Proceedings.

Enhancing the Shear Performance of Carbon Textile Reinforced-UHPC I-Beams through Web-Flange Detailing: A Multi-Scale Experimental Investigation

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Abstract. The combination of Textile-Reinforced Concrete (TRC) and Ultra-High Performance Concrete (UHPC) enables the creation of lightweight and durable thin-walled structural elements. While the flexural behavior of TRC I-beams has been the focus of several studies, their load-bearing capacity is often governed by a premature failure at the web-flange junction. With the shear behavior of such I-section beams remaining less understood, this study presents an experimental investigation of different web-flange connection details to evaluate their effect on structural performance. The methodology is based on a multi-scale experimental program. A pull-out test, designed to represent the web-flange junction, is used to characterize the local behavior of the connection details. Subsequently, full-scale Carbon Textile-Reinforced UHPC (CTR-UHPC) I-beams featuring distinct anchorage strategies are tested under a shear-critical three-point bending configuration. The results demonstrate a clear correlation between the junction's anchorage detail and the overall shear capacity of the beams. An improved connection detail mitigated the abrupt debonding failure, leading to an increase in both load-bearing capacity and deformation capability. The incorporation of short PVA fibers also provided post-cracking residual strength. This study concludes that the shear performance of CTR-UHPC I-beams is directly governed by the detailing of the web-flange connection. The experimental data presented serves as a valuable reference for the future development and validation of analytical models.

Keywords: Textile-Reinforced Concrete (TRC); Ultra-High Performance Concrete (UHPC); Web-Flange Junction; Shear Behavior; Anchorage.

See Full Paper in the Proceedings.

Influence of fabric manufacturing techniques on the tensile capacity of textile reinforced concrete (TRC)

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Abstract. Conventional steel reinforcement susceptibility to corrosion adversely effects sustainability of reinforced structures. Advanced materials such as textile-reinforced concrete (TRC), with their high tensile strength, corrosion resistance, lightweight properties, and potential for low-emission construction solutions, are becoming increasingly interesting in the realm of reinforced concrete. A range of test setups are employed to characterise the mechanical properties of textile-reinforced concrete, yet the influence of differing setup realisations on mechanical performance remains uncertain. A round robin test series was conducted to evaluate the accuracy and precision of measurement methods across participating laboratories, identify discrepancies in results, and enhance the reliability and comparability of test outcomes. Concrete specimens were reinforced with basalt and carbon textiles which were manufactured using different methods, namely (a) warp knitting and (b) tailored fiber placement (technical embroidery. In total 20 specimens per each lab were subjected to uniaxial tensile to evaluate mechanical properties. The results reveal a high accuracy of already established setups to determine uniaxial tensile response of TRC.

Keywords: Textile Reinforced Concrete (TRC), Sustainable Construction, Testing methods, Round Robin, Tensile Strength

See Full Paper in the Proceedings.

Bond behavior in Carbon and Basalt Textile-Reinforced Mortar Composites

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Abstract. Textile Reinforced Mortar (TRM) composites have emerged as promising strengthening solutions for masonry and concrete structures. However, composite performance is highly governed by bond characteristics between textile reinforcement and mortar matrix, making the understanding of stress transfer mechanisms crucial for design optimization and structural applications.

The present study investigates the textile-matrix bond characteristics of two different textile reinforcements embedded in mortar matrix through experimental pull-out testing. Carbon textiles (uncoated) and basalt textiles (SBR-coated) were examined with varying bond lengths of 40, 80, and 120 mm to evaluate the influence of embedment length on bond performance. Pull-out tests were conducted using TRM coupons where the applied load was transferred directly from the composite system to the textile fibers rather than directly to the textile, providing a more realistic representation of stress transfer mechanisms encountered in real-case strengthening applications.

Experimental results demonstrate the critical role of bond in TRM composite performance and reveal distinct characteristics between the two textile types. The uncoated carbon textiles and coated basalt textiles exhibited different bond-slip relationships influenced by their surface properties and textile-matrix interaction mechanisms. Bond stress and effective bond lengths were successfully determined for both textile materials, providing essential design parameters for practical applications.

Keywords: Textile Reinforced Mortar, Bond, Pull-out, Carbon, Basalt, Bond Length.

See Full Paper in the Proceedings.

DEVELOPMENT OF DURABLE E-GLASS TEXTILE REINFORCED CEMENTITIOUS COMPOSITES THROUGH CARBONATION

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Abstract

This study investigates the durability of textile reinforced cementitious composites (TRC) made with E-glass textiles, embedded in fine-grained cement concrete matrices with supplementary cementitious materials (SCMs) and using locally-available aggregates. Although E-glass is an inexpensive material for TRC, performance issues due to degradation in alkaline environment, typical of cementitious matrices. To overcome this, the current approach combines the concept of carbonation in conjunction with low carbon binders to create a low pH environment. The study is comprised of 4 experimental programs: (1) Durability characterisation of E-glass textiles under exposure to different pH conditions; (2) Development of low pH matrix through carbonation; (3) Assessment of mechanical performance of composites with the developed matrices; and finally, (4) Assessment of durability of the E-glass composites under accelerated aging, both with and without carbonation. The matrices investigated include those with ternary blends of ordinary portland cement (OPC) with fly ash and silica fume (OFAS-CS), OPC with ground granulated blast furnace slag (GGBS) and silica fume (OGSS-CS), and OPC with limestone calcined clay (LC2) cement (OLC2-CS) with compressive strengths of 40-55 MPa, maintaining workability as a performance requirement in mix formulation. Accelerated carbonation leads to the reduction in the pore solution pH, with OGSS-CS showing fastest carbonation. Tensile tests after accelerated aging showed significant loss in ultimate strength in the uncarbonated composites, with OGSS-CS and OLC2-CS based composites exhibiting maximum deterioration. On the other hand, carbonated composites exhibited significant strength retention, with the OGSS-CS mix showing high residual strength.

Keywords: Low-carbon binders, coated E-glass textiles, textile reinforced concrete, carbonation

FLEXURAL RESPONSE OF MINERAL-IMPREGNATED TEXTILE REINFORCED CONCRETE

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Abstract. Textile Reinforced Concrete (TRC), due to its outstanding properties, including good resistance to corrosion, low carbon footprint, excellent mechanical performance etc, has been received a growth attention in recent years. On account of the unique configuration of multifilament fibre yarn exited in TRCs, i.e., hundreds or thousands of continuous filaments in one single yarn, concrete matrix containing relatively lager particles is difficult to penetrate the interior of fibre yarn. It results in a poor stress transmission from matrix to fibre filaments and, thus, inferior utilisation of fibre filaments. For this, a pre-process on fibre yarn, i.e., polymer-impregnation, was introduced in the manufacturing of TRC composites, in which the fibre yarn was firstly impregnated by polymer-based material and forming a monolithic unit before embedding in concrete matrix. Nevertheless, because of the chemical incompatibility to concrete matrix and poor high temperature resistance of polymer, polymer-impregnated TRCs presented poor bonding between impregnated textile and concrete matrix, and degraded mechanical performance after exposure to high temperature. Therefore, impregnation based on mineral-based materials, which possess excellent compatibility to cementitious matrix and stability to high temperature, are rising. This paper presents a preliminary study about evaluating flexural performance of TRC plate reinforced with mineral-impregnated fabric mesh.

Keywords: Textile reinforced concrete, Mineral-based impregnation, mechanical performance, carbon fibre.

See full paper in the proceedings.

STRUCTURAL PERFORMANCE OF TRC TRUSS STRUCTURES UNDER STATIC AND DYNAMIC LOADING

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Abstract

Textile-reinforced concrete (TRC) offers innovative possibilities for lightweight and sustainable structural systems. Building on our previous research, which demonstrated the feasibility and efficiency of concrete trusses reinforced with 3D AR-glass textiles under four-point bending, this study deepens the investigation into advanced TRC truss designs and loading tests.

This work explores a novel truss configuration specifically designed according to a topology optimization of a beam under three-point bending. The experimental campaign includes flexural tests on the TRC truss beams, and characterization tests on the composite material level. The composite section includes fine-grained, high-performance concrete matrix and 2D carbon textiles. Additionally, the effect of incorporating short fibers into the matrix is also evaluated. A key objective is to assess both the static and dynamic flexural performance of the new truss design. Comparative testing with TRC beams with rectangular cross-sections will provide additional insight into the relative advantages of truss-based designs in terms of strength, stiffness, and material savings.

The outcomes of this study are expected to contribute to a more robust design methodology for TRC truss structures. By integrating experimental testing with manufacturing considerations, the research aims to bridge the gap between conceptual innovation and practical feasibility, ultimately promoting the use of TRC trusses as a sustainable solution in structural engineering.

Keywords: Textile reinforced concrete (TRC); Truss structures; Flexural performance; Experimental investigation; Dynamic response; Cracking analysis

RESISTANCE OF COATED E-GLASS TEXTILES TO ALKALINE ATTACK

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Abstract. Textile Reinforced Concrete (TRC) is emerging as a high-performance, lightweight and durable alternative to traditional steel-reinforced concrete, having significant potential for applications in thin-walled structures, façade panels, and durable infrastructure components. E-glass textiles can make this more promising but their stability, in terms of aging-related loss of mechanical integrity and degradation of the matrix-yarn interface, raises concerns. The best way to mitigate the deterioration is with appropriate coatings. This study compares the influence of pH on the durability of E-glass textiles coated with Styrene Butadiene Rubber (SBR) and Polyvinyl Chloride (PVC). The textiles were exposed to two alkaline solutions for 7 days, each representing a distinct pH range. To examine morphological changes in the fibres and coatings post-exposure, Scanning Electron Microscopy (SEM) analysis was conducted. The results offer valuable insights on the advantages of PVC coatings to enhance the long-term performance of TRC in real-world applications.

Keywords: Textile reinforced concrete, E-glass fibres, alkaline exposure, durability.

See full paper in the proceedings.

Influence of the textile placement on the flexural behaviour of Carbon Textile Reinforced Concrete

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Abstract. The flexural behaviour of any reinforced concrete element is governed by its internal lever arm between compressive and tensile forces. This internal lever is influenced by the placement of the reinforcement. The accuracy of reinforcement position becomes far more crucial inside thin Textile Reinforced Concrete (TRC) sections due to their slenderness compared to steel-reinforced concrete cross-sections, as only millimetres could alter the TRC's mechanical and cracking behaviour.

The aim of the present study is to quantify the influence of textile placement tolerances on the flexural behaviour of TRC. To do so, carbon textile reinforced concrete specimens of 50 mm thickness were cast with varying position of the fibre textiles inside the cross-section, hence shifting the neutral axis. Three different series were manufactured with varying mortar bottom cover of 8 mm, 5 mm and 3 mm, respectively. All samples were tested under four-point bending, and displacement and cracking behaviour were monitored by Digital Image Correlation (DIC). Additionally, the responses were compared to a numerical, layered composite model. The results showed that raising the textiles within the section significantly worsened the cracking pattern, while the textile position shift of up to 10% of the section's thickness did not alter significantly the bending stiffness.

Keywords: carbon reinforcement, cementitious composites, concrete cover, manufacturing tolerance, mechanical behaviour, Textile Reinforced Concrete

See Full Paper in the Proceedings

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NON-DESTRUCTIVE CHARACTERISATION OF CONSTRUCTION MATERIALS AND PROCESSES

SECONDARY IMBIBITION AS A NOVEL DURABILITY INDICATOR AND ITS EFFECT ON EXTERNAL DEFORMATIONS IN CONCRETE

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Abstract

Due to the high costs for maintenance and repair of concrete structures, there is an increasing interest in developing more durable constructions with a reduced environmental impact. A lot of research has been focusing on blended cements with supplementary cementitious materials. The performance of these blended cements is often investigated using the primary imbibition rate, or sorptivity, mainly caused by capillary forces. However, since this parameter is determined after 24 hours up to 1 week of contact with water, it does not describe the long-term behavior during the service life of a structure. Therefore, in this research, the secondary imbibition rate (SIR), possibly driven by diffusion, was studied as an indicator of long-term performance, which can provide a better understanding of the deterioration processes and provide valuable input for life-span modelling. Furthermore, the external deformations of the samples during the capillary water uptake, due to the swelling of calcium silicate hydrate (C-S-H), were measured. To do this, cylinders (diameter 100 mm, height 100 mm) of 6 concrete mixes with 3 different cement types (CEM I, CEM II/A-LL and CEM III/A) and 2 different water-to cement (w/c) ratios (0.4 and 0.7) were cast and cured for 28 days before starting the capillary imbibition test. The deformations during water uptake were measured using strain gauges. The results showed that the w/c has a significant impact on the length of the primary imbibition period. In mixes with a w/c of 0.7 the secondary imbibition period was reached after 1 month, while mixes with a w/c 0.4 had not reached the end of the primary imbibition after 1 year. Furthermore, the interaction between the cement type and w/c had a significant impact on the imbibition rate. The strain gauge data provided a good insight into the external deformations during water uptake in concrete.

Keywords: Concrete durability; secondary imbibition; deformations.

DESIGNING A SEMI-AUTOMATED CHARACTERIZATION FRAMEWORK FOR STRUCTURAL REUSE OF CONCRETE ELEMENTS

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Abstract. The structural reuse of reinforced concrete elements offers substantial ecological benefits by reducing demolition waste and the demand for new materials. Yet, its practical application is limited by the absence of reliable methods to assess the residual load-bearing capacity of reclaimed components. This paper presents a conceptual framework for a semi-automated testing approach that combines non-destructive testing (NDT) and low-intensity load testing (LILT). Robotic platforms are used to acquire reinforcement data with Ground-penetrating radar, while controlled loading procedures provide deformation responses below failure thresholds. These results are integrated with modeling approaches, including analytical evaluation based on the shear crack propagation theory (SCPT), to validate structural behavior and to extrapolate remaining capacity. The framework emphasizes standardized yet adaptable testing routines that balance efficiency, reliability, and non-destructiveness. By laying the foundation for replicable protocols in (p)refabrication facilities or mobile applications on-site, this work contributes to enabling structural reuse of reinforced concrete elements as a scalable strategy within circular construction.

Keywords: Structural reuse, concrete elements, non-destructive testing, automation, capacity assessment, circular construction

See Full Paper in the Proceedings

Non-destructive Evaluation of Damage Progression in GFRP-bar Reinforced Concrete Beams Through Multi-Technical Analysis

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Abstract: Glass fibre-reinforced polymer (GFRP)-reinforced concrete is a next-generation structural material using corrosion-resistant GFRP bars as reinforcement. This study investigates the damage progression and failure mechanisms in Glass Fibre Reinforced Polymer (GFRP)-bar reinforced concrete beams through non-destructive techniques, including Acoustic Emission (AE) and Digital Image Correlation (DIC). The research focuses on identifying critical failure precursors by analyzing AE time series, employing innovative methods such as the Method of Critical Fluctuations Based (MCF-B), Natural Time Analysis, and AE Entropy. Experimental results reveal a strong correlation between stick-slip behavior at the GFRP-concrete interface and AE amplitude features, highlighting the transition from tensile to shear cracks as the primary failure mode. The MCF-B method and Natural Time Analysis demonstrate high efficacy in detecting impending structural failure, while AE Entropy provides insights into the disorder and instability of the material as it approaches collapse. Additionally, the DPH index offers complementary information for AE data interpretation. These findings demonstrate that AE and DIC can serve as powerful tools for real-time structural health monitoring, contributing to sustainable infrastructure assessment through innovative materials and non-destructive characterization techniques.

Keywords: Glass Fibre Reinforced Polymer; Non-destructive Testing; Acoustic Emission; Digital Image Correlation; Failure Precursor; Method of Critical Fluctuations.

Geometric and material parameters in the manual draping of carbon textiles on waterbomb module

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Abstract. The integration of geometry and material behaviour, alongside the pursuit of sustainability and efficiency in construction processes, aims to enable the development of structurally optimized and resource-efficient systems that meet the demands of modern architectural and engineering applications. An emerging research direction involves the integration of origami-inspired geometries into textile-reinforced concrete (TRC), offering new pathways for lightweight and material-efficient construction. This study investigates the drapability and deformation behaviour of biaxially reinforced non-crimp carbon fabrics when manually shaped into waterbomb tessellation modules. Two distinct waterbomb geometries - differing in internal folding angles - are tested using various carbon textile architectures to assess their formability and structural performance. Initially, individual modules of the waterbomb are folded to evaluate the interaction between textile architecture and geometric complexity. Subsequently, a system of three connected modules is constructed to observe the cumulative effects of geometry and material on global and bigger scale draping behaviour. Key parameters such as undulation, gaps, loop formation, and fibre displacement are analysed for each configuration. The results highlight the influence of textile architecture, internal folding angle of the origami geometry, and scale on the foldability and surface quality of the reinforcement. This study contributes to the development of optimized tessellated textile configurations for integration into TRC components and underscores the importance of geometry–material compatibility for future automated forming processes.

Keywords: Textile Reinforced Concrete (TRC), Origami-based structural design, Drapability of non-crimp fabrics, Tessellated reinforcement geometry, Carbon fibre textiles, Geometry-material compatibility

See Full Paper in the Proceedings.

MONITORING OF HETEROGENEITY IN CEMENTITIOUS MATERIALS BASED ON DISPERSIVE ULTRASOUND

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Abstract

Elastic waves, in the form of ultrasound are widely utilized to assess the structural integrity of cementitious materials. Wave velocity and attenuation, among other parameters, provide valuable insights since they correlate with the material's stiffness and heterogeneity. However, while they are employed for initial performance assessments, the full potential for in-situ inspections has not yet been achieved. Specifically, lower-than-expected wave velocities cannot be directly linked to particular deterioration mechanisms or the size of heterogeneities. This limitation arises from the inadequate sensitivity of traditional pulse velocity to early damage indicators, challenges in interpreting waveforms related to structural conditions, and technical issues related to acoustic coupling. This paper illustrates that a thorough interpretation of ultrasonic dispersion could lead to a reliable evaluation of typical void sizes, enabling maintenance decisions based on engineering principles rather than solely on less accurate empirical correlations between pulse velocity and concrete quality or strength. The role of theoretical investigations in explaining the behavior observed through experiments is emphasized, along with the critical influence of applied frequency due to the interaction between wavelength and the size of heterogeneities or voids. Simulated damage in the form of light particles, as well as realistic durability attacks are considered as sources of damage for the evaluation of the ultrasonic dispersive signatures.

Keywords: Elastic waves, dispersion, damage, cracking, inspection.

STUDY OF PH PREDICTION TECHNIQUE FOR CARBONATED CONCRETE THROUGH CONCRETE COMPOSITION ANALYSIS

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Abstract

This study investigates a pH prediction technique for carbonated concrete based on detailed analysis of concrete composition, focusing on ordinary Portland cement (OPC) and fly ash (FA) blended systems. Accelerated carbonation experiments were conducted on cement pastes containing either 100% OPC or 20% FA substitution, simulating aggressive carbonation conditions. The chemical and phase changes in the pastes were characterized using thermogravimetric-differential thermal analysis (TG-DTA) and X-ray fluorescence (XRF), while pH measurements were performed on powdered samples extracted at various depths from the specimen surface. Results demonstrated that carbonation significantly lowered pH at the surface layer, with values dropping below 12, while inner layers retained higher alkalinity. XRF analysis revealed increased CO_2 and decreased CaO content at carbonated surfaces, correlating with the observed pH reduction. Strong negative correlations (correlation coefficients ≥ 0.84) were established between surface CO_2 content and pH, while CaO content showed a positive but slightly weaker correlation. TG-DTA results confirmed that the decomposition of calcium carbonate and calcium hydroxide corresponded with changes in pH, with the calcium carbonate content exhibiting a strong negative correlation to pH (correlation coefficient $\geq$ 0.86). The study proposes that pH in carbonated concrete can be reliably predicted through quantitative analysis of CO_2 and CaO ratios obtained via XRF and TG-DTA, offering a non-destructive approach to assess carbonation depth and the durability of concrete structures. This method is particularly advantageous for evaluating aging nuclear power plant concrete, where minimizing structural damage during sampling is critical. The findings provide a foundation for improved service life prediction and maintenance planning of reinforced concrete exposed to carbonation environments.

Acknowledgements

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Keywords: concrete, durability, fly ash, carbonation, pH

Monitoring heat-damaged TRM-confined concrete through NDTs

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Abstract. Understanding the behavior of confined concrete elements under extreme thermal conditions is essential for structural safety assessment and fire resistance evaluation. Textile Reinforced Mortar (TRM) confinement systems are increasingly used to enhance concrete performance, but their behavior after high temperature exposure still requires thorough investigation. Acoustic emission (AE) techniques provide valuable non-destructive monitoring capabilities for damage assessment and failure mechanism identification in structural systems. In this context, this study investigates the mechanical behavior and damage evolution of TRM-confined concrete specimens subjected to high temperature exposure through acoustic emission monitoring. Concrete specimens were confined with carbon TRM composites and subsequently exposed to high temperatures ranging from ambient conditions to 600 °C. Following thermal exposure, the specimens underwent uniaxial compression testing while AE signals were continuously monitored throughout the loading history. The experimental program aimed to evaluate the residual properties of TRM-confined concrete after high temperature damage and assess the capability of AE techniques to identify different damage mechanisms and failure stages.
Results demonstrate that high temperature exposure significantly influences the mechanical properties of TRM-confined concrete elements, with particularly catastrophic effects observed at 600°C exposure. The elevated temperature caused significant degradation in both the concrete matrix and the TRM confinement system, affecting the overall behavior and load-bearing capacity. Acoustic emission monitoring proved effective in monitoring damage initiation stages and different failure mechanisms across different high temperature exposure scenarios.

Keywords: Acoustic emission, TRM confinement, high temperature, concrete, carbon fibers, damage monitoring.

See full paper in the proceedings.

AIR-COUPLED ULTRASONIC ASSESSMENT OF CONCRETE DAMAGE AND REPAIR

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Abstract

The built environment comprises an increasing number of aged and damaged concrete infrastructure. In view of prolonging the lifetime of these structures and contributing to the sustainable development goals, timely and effective repairs are needed. Over the past decades, non-destructive monitoring has gained increased attention, thanks to the early detection of damage without interference with the mechanical performance. More specifically, the adoption of elastic (ultrasonic) waves has emerged as a promising technique for the evaluation of concrete quality, thanks to its sensitivity to the elastic properties of the substrate. Up to now, mostly coupled ultrasonic transducers were utilized, necessitating a physical connection to the element under study. The manual coupling of sensors not only increases the time needed for performing the evaluation but also can disrupt data because of coupling variability between measurements. Therefore, the use of contactless transducers provides a solution. However, the impedance mismatch between substrate and air causes a strong attenuation of the ultrasonic signals, thereby limiting the signal-to-noise ratio. Previous studies have shown that air-coupled ultrasonic measurements are improved through measurement set-up, including the positioning of the transducers and the accurate determination of the lift-off distance, as well as a systematic analysis procedure to obtain reliable results. Within this study, the potential of air-coupled ultrasound for the detection of damage and the evaluation of repair within concrete is further explored, aiming for a fully air-coupled, automated assessment. Concrete beams were evaluated in an intact, cracked and repaired state, the latter obtained after epoxy injection. The evaluation comprised a surface wave set-up, including contactless emitter and a set of 7 MEMS as receivers. The receivers were moved along the length of the beam to characterize its entire volume. The results show the sensitivity of ultrasound to the present damage and repair, and its location within the studied elements.

Keywords: Structural Health Monitoring; Air-coupled Ultrasound; Concrete; Repair.

In Situ Experiments with Acoustic Emission and X-Ray Imaging to Measure Damage Processes in Concrete

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Abstract. Quantitative measurements of fracture and damage in cement-based materials has historically been a challenge due to complex and compounding phenomena occurring over a wide range of length and time scales. In the present work, two experimental techniques are combined in a single test: x-ray imaging, and acoustic emission monitoring. In x-ray imaging, the spatial resolution is high, but the temporal resolution is dependent on the image acquisition rate, and tends to be low. Conversely, in acoustic emission monitoring, the spatial resolution is limited, but the temporal resolution is extremely high. We find in combining the techniques in a configuration under which load and deformation are applied, we can exploit the strengths of the two techniques to not only better understand damage evolution, but to set the stage for more advanced techniques in which x-ray computed tomographic imaging, with its very high spatial resolution, can be triggered by acoustic emission signals. Preliminary tests show that acoustic emission signals can be matched to specific cracking phenomena in concrete, however the advancement of tomographic imaging is likely to provide the greatest potential for new insight.

Keywords: Concrete, Damage, Acoustic Emission, X-ray, Tomography

See full paper in the proceedings.

ON-DEMAND CURING CONTROL OF CONCRETE USING ACOUSTIC EMISSION MONITORING

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Abstract

The quality and performance of concrete depend heavily on the mixing and curing process. Changes in relative humidity and temperature can lead to premature drying and cracking. Monitoring and controlling concrete curing are essential in preventing these issues. Shrinkage cracking can be mitigated by using SuperAbsorbent Polymers (SAPs), which provide internal curing protecting the material after casting. Internal curing is beneficial, however, the SAP kinetics within the bulk are difficult to trace. Recent research has shown that the release of SAP water (desorption) during curing coincides with high Acoustic Emission (AE) recordings, allowing for monitoring and control of the internal curing process. This study introduces the upscaling of an active curing control methodology which uses AE to optimize internal curing in SAP concrete. At the moments dictated by AE, the concrete surface is wetted, allowing for controlled activation/deactivation cycles of SAPs. Restrained slab elements are actively controlled to extend internal curing, improve hydration, and mitigate shrinkage cracking. Results show that the SAP desorption duration was tripled compared to conventional SAP concrete, demonstrating the method's capacity to significantly enhance curing while fully monitoring SAP dynamics. Microscopy at 7 and 28 days revealed narrower cracks in the actively controlled specimens compared to conventional (SAP) concrete, demonstrating the possibility to control shrinkage and enhance durability in large surface elements. The approach promotes sustainable construction by minimizing early-age damage and extending service life, while reducing the demand for materials, labor, and long-term maintenance.

Keywords: acoustic emission, active curing control, superabsorbent polymers, crack control

Detection of different orientation of internal cracks in concrete utilizing impact echo data analysed by AI based on un/supervised deep learning

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Abstract. The number of aging concrete infrastructures has dramatically increased with the past urban development. Deterioration is primarily caused by cracking, particularly internal cracks in concrete, which are not visible through visual inspection on the surface. In existing structures, internal cracks can be formed in various orientations, such as diagonal cracks, which present additional challenges in damage evaluation. Crack propagation is a major concern, as it can significantly compromise structural integrity, durability, and overall performance of concrete structure. Non-Destructive Testing (NDT) techniques, such as the Impact-Echo (IE) method, are commonly used to evaluate damage and estimate repair conditions. In this study, internal crack was artificially introduced using starch-type polysaccharide sheet to simulate interior damage in a real situation. Typically, internal conditions are assessed based on waveform characteristics obtained from elastic wave propagation in applying IE method. For interpretation of waveform data, it is commonly converted to the frequency domain using Fast Fourier Transform (FFT) analysis. While horizontal internal cracks typically result in a clear peak corresponding to crack depth, diagonal cracks often produce multiple dominant frequencies, which require more complex data interpretation. To address this, AI-based analysis utilizing supervised deep learning models with frequency domain data is proposed to evaluate and estimate the geometrical information of crack inside concrete. However, labelling datasets for training supervised models is challenging in the context of aging infrastructures, as these structures often lack specific details due to their unique and varied characteristics. To overcome this limitation for preparing datasets, this study also proposes the application of unsupervised deep learning models as a potential solution. The unsupervised approach is validated through comprehensive evaluation, demonstrating its effectiveness in detecting and characterizing internal defects in concrete specimens.

Keywords: Concrete, Non-Destructive Testing (NDT), Impact-Echo (IE), Internal crack, Artificial Intelligence (AI), Deep Learning (DL).

See full paper in the proceedings.

Dielectric response of concrete under varying salt concentrations: a Maxwell–Wagner perspective

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Abstract. This study investigates the dielectric behavior of cement-based concrete systems with varying salt concentrations from the perspective of Maxwell–Wagner interfacial polarization. Cuboid concrete specimens were cast with four embedded stainless steel (SS) plates acting as probes in a Wenner-type configuration to enable non-destructive electrochemical impedance spectroscopy (EIS). The specimens contained no reinforcing steel and were free from carbonation to isolate the dielectric response from corrosion-related phenomena. EIS measurements were conducted over a wide frequency range (10 mHz to 2 MHz) in a temperature and humidity-controlled environment. The influence of increasing salt concentration introduced as NaCl by weight of cement was analyzed in terms of changes in bulk resistance, capacitance, and interfacial polarization effects. The Nyquist and Bode plots exhibited frequency-dependent dispersion indicative of Maxwell–Wagner-type relaxation, with pronounced modifications in the low-frequency domain as salt content increased. Equivalent circuit modelling revealed a transition from simple RC behavior to systems requiring diffusion elements, consistent with ionic accumulation and interfacial charge storage.

Keywords: Electrochemical impedance spectroscopy; dielectric behavior; Maxwell-Wagner; Wenner probe.

See full paper in the proceedings.

IMPEDANCE-BASED MONITORING OF RHEOLOGICAL PROPERTY EVOLUTION IN CEMENTITIOUS BINDERS FOR 3D CONCRETE PRINTING

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Abstract. Real-time monitoring of structural build-up is critical for robust 3D concrete printing (3DCP). We evaluate electromechanical impedance (EMI) sensing with embedded piezoelectric (PZT) sensors to track early-age structuration of cementitious binders, a key phenomenon for 3DCP. Cement pastes (CEM I 42.5 R) spanning water-to-cement ratios w/c = 0.32, 0.36, 0.40 and a phosphate-retarded paste were cast with embedded sensors. Electrical impedance (EI) measurements were recorded from casting to 4 h for the w/c series (0-7 h for the retarded mix) and were normalized to each sensor's in-air baseline. The fundamental resonance was very sensitive to the surrounding medium: immediately after embedding, the conductance peak decreased and the resonance shifted to lower frequency, followed by continued attenuation during the nominal dormant period. Over the hydration window studied, peak-conductance amplitude was more sensitive to microstructural changes than resonance-frequency shift, and this amplitude-based metric correlated with reference measurements: small-amplitude oscillatory shear (SAOS) rheometry and Vicat penetration. The rate of change in peak-conductance amplitude ranked with composition (WC32 > WC36 > WC40). The retarded mix showed an unusual early build-up signature that preceded the hydration-driven percolation knee seen in rheology, which was reflected in the conductance trends. The mapping between shear modulus and conductance-derived features was nonlinear. EI spectrum responded from the time of casting, providing the earliest actionable indicator for process control. Overall, this preliminary study with standard cement pastes indicates that the EMI sensing offers a sensitive, embedded, and physically interpretable route to in-situ monitoring of fresh-state evolution, with potential to define practical setpoints (for example, interlayer wait times), while Vicat and rheology serve as benchmarks and calibration companions.

Keywords: 3D Concrete Printing, Piezoelectric Sensors, Electromechanical Impedance (EMI), Shear modulus, In-line Sensing, rheology monitoring

See full paper in the proceedings.

UNVEILING THE STEEL–CONCRETE INTERFACIAL CHARACTERISTICS INFLUENCING CHLORIDE-INDUCED CORROSION INITIATION USING X-RAY COMPUTED TOMOGRAPHY

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Abstract

Chloride-induced corrosion is one of the most critical forms of degradation in reinforced concrete (RC). In Western European countries, where many buildings and infrastructures are approaching (or even exceeding) the end of their designed service life, the demand for maintenance, repair, and eventual demolition or reconstruction continues to grow. There is an urgent need for reliable service life models that can accurately predict when maintenance or the end of a structure's serviceability and safety will occur. Such models would enable targeting the needed maintenance interventions, optimizing the use of resources, and help reducing the environmental footprint associated with cement production. To develop these models, a deep understanding of the fundamental processes driving chloride-induced corrosion in RC is essential. Among others, recent studies suggest that heterogeneities at the steel-concrete interface (SCI), particularly macro voids, play a crucial role in initiating corrosion. The moisture content at the SCI, along with the moisture conditions and air-liquid configuration within the interfacial air voids, appears to drive the onset of corrosion. Furthermore, the presence of a thin (few micrometers) cement paste layer between the steel and air voids at the SCI may also influence how moisture ingress occurs in void volumes and, also, the favorable air-liquid configuration therein. To assess the impact of this air-liquid configuration on chloride-induced corrosion initiation, X-ray computed tomography (XCT) has been employed in this study. XCT is an ideal tool for this investigation due to its non-destructive nature, allowing for the study of corrosion mechanisms in an undisturbed state over time. Additionally, XCT can resolve moisture within concrete air voids, providing valuable insight into the corrosion process. The goal of this study is to elucidate the influence of SCI characteristics, specifically macro voids and their internal air-liquid distribution, on the complex, coupled processes leading to the initiation of chloride-induced corrosion in steel embedded in concrete thanks to XCT.

Keywords: corrosion, chloride, reinforced concrete, X-ray computed tomography, durability



BITUMINOUS MATERIALS: characterisation modelling and analysis to support circular economy

INTERMEDIATE-TEMPERATURE CRACKING RESISTANCE OF BITUMINOUS MIXTURES BASED ON THE SEMI-CIRCULAR BENDING TEST: IMPACT OF TEST CONDITIONS AND NOTCH DIMENSIONS

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Abstract

The semi-circular bending (SCB) test is widely accepted as a fast and promising method for evaluating the intermediate-temperature cracking resistance of bituminous mixtures in laboratory settings. Such a test is imperative to ensure the durability and cost-effectiveness of asphalt pavements. Its importance is further magnified by high decarbonisation goals in asphalt mixtures, which aim to maximize the incorporation of Reclaimed Asphalt (RA) and the use of alternative binders. Enhanced circularity and new materials necessitate more accurate and precise screening test protocols within the framework of balanced performance assessment. Currently, different protocols are described in previously published works and standards (EN, ASTM and AASHTO), in which different metrics, test conditions and notch dimensions are described. The goal of this study is to showcase the impact of those aspects on the precision and discriminative power of the SCB test. More specifically the methodology of this study focuses on three axes: 1) Impact of test temperature (15 or 25°C) and loading rate (5 or 50 mm/min); 2) Impact of notch depth: 10 or 15 mm; 3) Impact of data analysis method (Fracture toughness – K_{IC}, Flexibility Index – FI, Cracking Resistance Index – CRI, Balanced Cracking Index – BCI). A final test protocol will be defined and further validated to evaluate the discriminative power of the SCB test. To do so, different surface layer bituminous mixtures will be considered to evaluate the sensitivity of the test in terms of bitumen content and RA incorporation.

Keywords: SCB test; Cracking resistance; Fracture; Bituminous mixtures; Reclaimed Asphalt;

MULTI-TECHNIQUE CHARACTERIZATION OF RECLAIMED ASPHALT PAVEMENT SYSTEMS WITH BIOBASED AND SECONDARY MATERIALS

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Abstract

Reclaimed Asphalt Pavement plays a central role in sustainable road construction by reducing the demand for virgin materials and offering economic feasibility. Current efforts in pavement engineering are shifting from single-use recycling towards enabling multiple recycling cycles, including systems modified with biobased additives, rubber from end-of-life tires, and other secondary resources. To ensure their viability, these materials must demonstrate recyclability and durability without compromising environmental performance. However, conventional RAP binder analysis relies on solvent-based extraction methods, which can alter binder chemistry and have significant health and environmental risks due to the hazardous nature of the solvents used.

This study introduces a multi-technique characterization framework that eliminates the need for binder extraction, enabling direct analysis of RAP systems with alternative materials. Fourier Transform Infrared Spectroscopy was used to identify functional groups related to binder chemistry, ageing, and the incorporation of biobased components. Laser-Induced Breakdown Spectroscopy provided rapid elemental analysis, detecting key elements (C, S, Si) as well as trace heavy metals such as Pb, which may influence stormwater and soil quality during the service life of road pavements. Thermogravimetric Analysis coupled with Mass Spectrometry was applied to assess thermal stability, degradation pathways, and gaseous phases. X-Ray Fluorescence quantified inorganic phases and aggregates composition, while complementary Loss on Ignition in oxidative atmosphere was used to account for volatile content and to correct XRF results, given the limitations of XRF in detecting light elements. Together, these techniques provide an integrated physico-chemical understanding of conventional, biobased, and rubber-modified RAP systems. The findings demonstrate that it is possible to study RAP directly, without the need for solvent extraction. Beyond characterizing the binder itself, the approach also reveals, and in some cases identifies, additives and trace elements that are present. This provides valuable insight into the complexity of RAP materials, their recyclability, and potential environmental impacts, while keeping the binder intact and avoiding distortions caused by traditional solvent-based methods. This framework improves accuracy compared to conventional solvent-based methods, although surface sensitivity of FTIR and calibration challenges should be considered.

Keywords: Reclaimed asphalt pavement, recycling, biobased binders, physico-chemical analysis, sustainable pavement materials

EVALUATING THE AGEING RESISTANCE OF INNOVATIVE ASPHALT MASTICS FOR DURABLE DIKE REVETMENTS

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Abstract

Hydraulic asphalt layers are a vital component of dike revetments in low-lying regions worldwide, providing essential protection against flooding and rising sea levels. As existing flood defence systems age and road administrations transition towards sustainable infrastructure, there is an urgent need to develop innovative asphalt solutions that enhance durability and promote the circular use of materials. Thus, the objective of this research is to evaluate the susceptibility to ageing of eight hydraulic mastic compositions (72 replicates), which were prepared using binders extracted from field cores obtained after five years of in-service performance. The cores were taken from eight distinct sections and the mastics were formulated using two types of filler: Wigro and a bio-based alternative. To simulate long-term performance, the mastics were evaluated under three ageing conditions: unaged; aged in a pressure ageing vessel (PAV) for 40 hours; and aged in a PAV under humidity conditions to replicate moisture-assisted ageing. Frequency sweep tests were conducted using a Dynamic Shear Rheometer (DSR) at temperatures ranging from 0 to 40 °C in 10 °C intervals and at frequencies ranging from 10 to 0.1 Hz. Master curves were plotted, and key performance parameters such as crossover frequency and the Glover–Rowe (G–R) parameter were evaluated. The results showed that mastics with higher filler dosages exhibited greater resistance to ageing in all conditions. This was attributed to the formation of a dense microstructure that restricted moisture ingress and preserved rheological properties. Conversely, mastics with a high recycled asphalt content (e.g. 70%) softened under moisture induced ageing, raising concerns over their durability. Although using recycled materials can offer benefits in terms of circularity, the proportion used should be carefully managed to avoid compromising the durability and crack resistance of dike revetments, thereby ensuring long-term sustainability.

Keywords: hydraulic asphalt, RAP, mastic, ageing, durability

MECHANISTIC-EMPIRICAL DESIGN FRAMEWORK FOR COLD RECYCLED ASPHALT PAVEMENTS

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Abstract

Cold recycled (CR) asphalt pavement technologies are widely utilized by numerous highway agencies for flexible pavement rehabilitation due to its cost and environmental benefits. Current mechanistic-empirical (M-E) design methods, however, lack robust characterization of these materials, often defaulting to assumptions that underestimate and overlook their partially bound, visco-plastic nature, thus leading to structurally inefficient or under/overly conservative designs. This study presents a comprehensive M-E framework grounded in extensive laboratory and field data, facilitating rational structural design and reliable performance prediction. Twenty (20) field sections encompassing a range of pavement material compositions, layer thicknesses, and traffic levels at distinct temperate regions within Minnesota in United States were identified and subjected to in-situ evaluations in terms of Falling Weight Deflectometer deflection tests, International Roughness Index (IRI) and rut depth measurements. Laboratory evaluation of over 50 mixtures, derived from as-built job mix formula and laboratory-formulated variations of the as-built job mix, included resilient modulus, indirect tensile strength (ITS), and triaxial shear strength, performed under controlled curing and seasonal temperature conditions to reflect in-situ conditions. Leveraging these field and laboratory evaluations, mechanical property prediction models were developed via machine learning algorithms; self-validating ensemble modelling and Support Vector Regression, enabling the estimation of resilient modulus, ITS, cohesion, and frictional angle from typical mix design parameters and construction features. By integrating field distress observations, laboratory material evaluations, and mechanistic analysis of the CR pavement structures, a rutting performance function was developed. This function leverages key material properties, critical pavement responses, and a mechanistic indicator known as the Deviator Stress Ratio (DevSR). Further, a DevSR threshold was proposed to distinctively limit early life rutting of the CR layer, additionally verified by a receiver operating characteristics (ROC) analysis. This performance-informed and data-driven framework supports the rational structural design of CR pavements, promoting cost efficiency and improved performance reliability.

Keywords: cold in-place recycling, stabilized full depth reclamation, prediction model, rutting performance function, mechanistic-empirical design

TOWARDS HARMONIZED DSC ANALYSIS FOR BITUMEN THROUGH INTERLABORATORY WORK WITHIN RILEM TC 295-FBB

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Abstract

Differential Scanning Calorimetry (DSC) is increasingly recognized as a valuable tool for characterizing the thermal behaviour of bituminous binders. However, inconsistent procedures, data interpretation methods, and equipment configurations have limited its broader application in bitumen research and specification. To address this, an interlaboratory effort was initiated through the work of Task Group 2 (TG2) of the RILEM Technical Committee 295-FBB, aiming to harmonize DSC testing and data analysis approaches. Six laboratories contributed datasets from modulated and non-modulated DSC experiments on a diverse binder matrix, including virgin binders, RAP/Rejuvenator blends, and SBS-modified binders across varying concentrations and aging levels. To guide the analytical direction, participating experts first shared insights into both effective and ineffective practices based on their prior experience. For instance, utilizing polynomial fitting on reversing heat flow, integrated with derivative analysis, helps improve the consistency of Tg determination. Several challenges were also recognized. Storage conditions, even under sealed or subzero environments, produced measurable shifts in Tg, underscoring the importance of standardized handling and testing windows. Nevertheless, when coupled with standardized protocols and advanced data processing, DSC testing has the potential to provide reproducible and insightful indicators of binder compatibility, ageing behavior, and multiphase heterogeneity in modified binders. To validate these expert hypotheses, the pooled DSC data, integrated with supplementary rheological or chemical data, were analysed using advanced multivariate analysis and machine learning (ML) techniques, including Principal Component Analysis (PCA) and Partial Least Squares Regression (PLSR). The results demonstrated the high reliability of DSC in distinguishing binder types, detecting ageing patterns, and correlating thermal behavior with other material properties. By combining empirical knowledge with data-driven validation, this study enhances interpretability and interlaboratory comparability of DSC results, laying a solid foundation for future round-robin studies and protocol standardization efforts.

Keywords: Bituminous binders, Differential Scanning Calorimetry, Interlaboratory study, Thermal transitions, Multivariate analysis, Binder ageing.

PERFORMANCE EVALUATION OF RECYCLED ASPHALT MIXTURES WITH ALTERNATIVE PAVING MATERIALS IN FINNISH ROAD NETWORKS

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Abstract

Pavement surface recycling has been used on Finnish roads for several years, primarily through two techniques: full-lane width treatment (remix) and partial-lane processing (rut-remix). Within a national research project, asphalt mixtures from four different road sections in Finland were rehabilitated using both methods. The materials studied included conventional asphalt and a wide range of alternative mixtures incorporating polymer-modified binders, aramid fibers, FEP elastomers, rubber additives, reclaimed asphalt shingles, steel slag, and soft binders adapted for Nordic climates. The mixture consisted of conventional asphalt concrete with a 16-millimeter nominal maximum aggregate size, except for steel slags that included both asphalt concrete and stone mastic asphalt. Core samples were extracted before and after recycling to evaluate the mechanical and durability performance of both the aged in-situ materials and their recycled counterparts. A comprehensive laboratory testing program was conducted at the mixture level to assess changes in properties due to the remix and rut-remix processes. The set of tests included strength in indirect tensile mode (dry and wet conditions), stiffness, Prall abrasion, and creep permanent deformation. These tests are intended to produce enough data to assess the quality requirements for the finished pavement as per the Finnish asphalt standard. The test results were compiled into a comparative database and analyzed using a scoring system to quantify the performance across material types and recycling methods. One key finding was the strong correlation between air void content and abrasion resistance, consistent across all materials tested. This aspect underlines the critical importance of achieving uniform compaction, particularly in recycled layers. The study offers practical insights into the behavior of recycled asphalt under cold-climate conditions, highlighting the performance variability introduced by different additives and recycling techniques. More broadly, it reflects the growing interest in sustainable and alternative paving solutions. This research aligns with the ongoing work of RILEM Technical Committee 323-APD, which supports the global advancement and assessment of innovative materials in pavement engineering.

Keywords: Asphalt recycling, Alternative paving materials, Cold-climate pavements

Investigating the Use of Calcium Lignosulfonate as a Sustainable Filler Alternative in Road Construction Materials

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Abstract. Lignin-derived additives are being increasingly explored as sustainable modifiers for bituminous materials, yet their performance varies widely depending on the chemical formulation and mode of incorporation. This study evaluates calcium lignosulfonate, a water-soluble derivative of the sulphite pulping process, as an alternative filler for asphalt and bituminous-stabilised materials (BSMs). In asphalt mixtures, replacing conventional cement filler with lignosulfonate reduced permanent deformation by up to 50% under high-temperature wet loading, indicating a substantial improvement in rut resistance relative to standard mixes. Conversely, when incorporated via the wet method as a binder extender, lignosulfonate softened the aged binder and increased its susceptibility to rutting. The investigation was subsequently extended to BSMs, where triaxial testing revealed that lignosulfonate provided only marginal cohesion benefits and did not enhance overall shear strength compared to the granular material. These findings suggest that calcium lignosulfonate is well-suited as a bio-filler in asphalt but is less effective as a cement replacement in BSMs under the curing conditions considered. Integrating lignosulfonate into asphalt, therefore, presents a viable pathway for valorising a pulp-and-paper byproduct while reducing reliance on energy-intensive cement fillers. Future work should assess curing protocols for BSMs and undertake detailed economic and life-cycle evaluations to support implementation at scale.

Keywords: Calcium lignosulfonate, Bio-filler, Asphalt mixtures, Bituminous stabilised materials (BSMs), Rutting resistance, Sustainable pavement materials.

See full paper in the proceedings.

ENHANCING SUSTAINABILITY IN PAVEMENT MATERIALS: A PREDICTIVE MODELING APPROACH

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Abstract

Natural materials used in pavement engineering, such as aggregates, are non-renewable resources, and they account for over 90% of the total mass of asphalt pavement. To promote sustainability and reduce the consumption of natural aggregates, this study investigates the use of sustainable materials as partial replacements for coarse aggregates in asphalt mixtures. A total of 63 experimental data records were collected from the literature to evaluate and predict the mechanical and durability performance of asphalt mixtures containing varying percentages of sustainable material replacement. The analysis focused on understanding how these substitutions influence key performance parameters of asphalt mixtures. The findings indicate that sustainable materials can effectively serve as alternative coarse aggregates, offering a promising pathway toward resource conservation and environmentally responsible pavement construction. Furthermore, it is possible to make preliminary predictions of suitable sustainable materials for asphalt mixtures based on their properties before conducting laboratory tests of asphalt mixture. This predictive approach can significantly reduce reliance on time-consuming trial-and-error mixture design, as traditional regression methods often fail to capture the complex interactions between sustainable materials and asphalt binder systems.

Keywords: Sustainability, Asphalt mixtures, Pavement materials, Modeling, Coarse aggregate replacement.

EXPERIMENTAL INVESTIGATION OF BITUMEN–AGGREGATE INTERFACIAL DEBONDING BEHAVIOR UNDER VARYING LOADING AND ENVIRONMENTAL CONDITIONS

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Abstract

Porous asphalt is widely used in the Netherlands for highway pavement construction; however, its long-term durability is often compromised by debonding at the bitumen–aggregate interface. In the mechanical investigation of bitumen–aggregate interfacial debonding, tensile testing using a column-shaped aggregate–bitumen–aggregate specimen enables direct characterization of interfacial failure behaviour, making it a commonly recommended test approach. However, existing studies have predominantly focused on comparing the interfacial bonding strength among different bitumen types, whereas the sensitivity of adhesion performance under varying loading and environmental conditions by the same bitumen remains insufficiently addressed. To investigate the influence of loading type and testing conditions on the interfacial mechanical behavior between bitumen-aggregate interface, this study conducts a systematic analysis under both monotonic and fatigue loading scenarios of bitumen with penetration 70. In the monotonic loading tests, a range of testing temperatures from 0 °C to 15 °C and pull-off strain rates from 1% to 5% were applied to investigate their effects on interfacial performance. The primary indicators used for analyzing mechanical behavior were the stress and the corresponding interfacial characteristic displacement length at the peak point on the stress–displacement curve. In the fatigue loading tests, a range of loading frequencies from 5 Hz to 10 Hz and load amplitudes from 5 N to 10 N were applied to investigate their effects on interfacial performance. The primary indicators used for analyzing mechanical behavior were the fatigue life and the corresponding maximum failure displacement. The experimental results indicate that under monotonic loading conditions, both temperature and pull-off rate have a significant effect on peak stress, while the characteristic displacement length remains relatively stable. Under fatigue loading, both fatigue life and maximum failure displacement exhibit clear variations in response to changes in loading frequency and load amplitude. The findings offer guidance for future meso-scale tensile testing regarding the selection of loading conditions and interpretation of results in interfacial debonding at the bitumen–aggregate interface.

Keywords: aggregate-bitumen interface; debonding behavior characterization; monotonic tension loading; fatigue loading.



CARBONATION AND CO2 UPTAKE IN COATED AND UNCOATED CEMENTITIOUS MATERIALS

CO_2 UPTAKE VIA CARBONATION IN BLENDED CEMENTS OVER DECADAL TIMESCALES

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Abstract

Traditionally viewed as a degradation mechanism, carbonation of concrete is also beneficial as it offsets historical CO_2 emissions. However, during the service-life of a structure, uncertainty persists on (a) the amount of CO_2 absorbed relative to its theoretical maximum — degree of carbonation (DoC), and (b) the rate at which this CO_2 is absorbed — carbonation rate. To address this uncertainty, we investigate 23 different cement pastes of varied compositions after up to 12 years of natural carbonation. We observe that all blended cements absorb less CO_2 than ordinary Portland cement (OPC) but carbonate 2-10 times faster. While OPC plateaus at most at 80% DoC, blended cements reach over 90% DoC quicker. Finally, we illustrate future cement use scenarios where blended cements absorb almost their full chemical CO_2 during their service-life. Through this work, we reframe concrete carbonation as an important CO_2 mitigation strategy.

Keywords: low clinker cements, CO_2 uptake, carbonation, carbonation rate, carbonation degree.

WHAT ABOUT THE CO_2 UPTAKE AFTER THE SERVICE LIFE OF CONCRETE STRUCTURE?

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Abstract

Thanks to carbonation, CO_2 emissions from concrete structures, mainly due to cement production, are partially reversible. Atmospheric CO_2 uptake occurs not only during the service life, but also after the end-of-life. After the crushing of concrete waste, recycled aggregates have a priori a non-negligible CO_2 binding rate. The latter is usually explained by the high specific area of recycled aggregates. However, to date, few studies have assessed the actual CO_2 uptake by recycled aggregates in their conditions of exposure after crushing, i.e., i) stockpile on the recycling platform during several weeks, ii) pavement sub-base (road applications are still the main use of recycled aggregates). In the present study, we present models set up to assess the CO_2 uptake in the storage phase, and then in the use phase. Models application is based on data determined using specially designed experimental methods, used to assess both the gas diffusion coefficient and the CO_2 binding capacity. Calculations show that in the storage phase, a several meter high stockpile of recycled aggregates should carbonate very little, since the carbonation depth would remain lower than a few centimetres. In the use phase, recycled aggregates are compacted in a road layer that carbonate quite slowly. The carbonation rate of such a layer is approximately ten millimetres per year$^{1/2}$, which is close to the carbonation rate of low-strength concrete. All these results suggest adopting a conservative approach in life cycle analysis, i.e., neglecting the CO_2 uptake by concrete after the end-of-life.

Keywords: Concrete, Carbonation, CO_2 uptake.

Evolution of pH and Oxygen Production in 3D Printed Concrete Mortars for Marine and Terrestrial Applications

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Abstract. 3D concrete printing (3DCP) offers new opportunities to create bioreceptive structures that support ecological colonisation. pH is a decisive factor because it controls the surface conditions where pioneer biofilms establish. There is no standard method to evaluate pH in relation to bioreceptivity. This study presents an initial assessment of pH development in 3D printed mortars and its link to early biofilm metabolic activity. A CEM I mortar, with and without an alkali-free accelerator, was cast into filament-like specimens. The specimens were exposed for six months to indoor, outdoor, and marine environments. Surface and bulk pH were measured to separate environmental interaction from internal carbonation. Biofilm productivity (photosynthesis and respiration) was evaluated through oxygen exchange measurements performed under controlled light regimes. Surface measurements reflected environmental effects more clearly than bulk values. Marine exposure caused the largest pH reduction and visible biofilm colonisation. Accelerated mixes consistently reached lower pH and higher biofilm productivity. These conditions indicate more effective bioreceptivity.

Keywords: pH measurements, Bioreceptivity, 3D Concrete Printing, Biofouling.

See Full Paper in the Proceedings

CARBON DIOXIDE SEQUESTRATION IN CONCRETE – A SIMPLIFIED UPTAKE ASSESSMENT VIA MUFFLE FURNACE

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Abstract

The reduction of concrete embodied carbon is a critical strategy in mitigating the growing global warming potential. Among the diverse portfolio of solutions, carbon capture, utilization, and sequestration (CCUS) technologies stand out as essential tools for reducing carbon dioxide emissions in the concrete industry. Concrete itself plays a pivotal role in this effort due to its inherent ability to naturally bind carbon dioxide with its alkaline compounds. Recently, the development of engineered carbonation solutions, which permanently sequester CO_2 within the cementitious matrix, has sparked significant interest. However, scaling these systems from laboratory experiments with cement paste to real-world concrete production introduces challenges in quantifying the carbon dioxide bound.

Currently, thermogravimetric analysis (TGA) is the most widely used technique for measuring CO_2 uptake. However, limitations in sample size often restrict the representativity of measurements, especially when aiming to capture the behaviour of larger batch volumes. To address this issue, a novel approach combining TGA with muffle furnace analysis has been proposed, allowing for a more comprehensive assessment of CO_2 sequestration in cementitious materials. The comparison was carried out in two stages: first, between two concrete batches produced using a CO_2-injection system – one carbonated during the mixing stage – and second, with three cement paste batches. Two different heating protocols were adopted to capture decomposition behaviour. One strategy involved isothermal heating steps at significant decomposition peaks' temperatures, while ensuring homogeneous temperature distribution throughout the sample. The other approach used isothermal steps across decomposition peaks, offering a complementary perspective on CO_2 release.

The findings revealed that while both methods are highly accurate in identifying and quantifying carbonates, they are less precise when applied to other hydration phases. Notably, the magnitude of weight loss measured in the muffle furnace was more pronounced than in TGA. This effect is most likely attributable to the isothermal heating steps required in furnace analysis. These results demonstrate that the complementary use of TGA and muffle furnace significantly strengthens the assessment of CO_2 sequestration efficiency in both concrete and cement paste, offering valuable insights for evaluating carbon dioxide uptake on more representative samples.

Keywords: Concrete, Carbon Capture and Utilization, CO_2 Uptake, Sustainability.

Key factors for understanding carbon dioxide uptake capacity in biochar-based cementitious materials

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Abstract. The construction industry, a major contributor to global CO_2 emissions, has explored innovative solutions to reduce its carbon footprint. A promising avenue is the integration of biochar, a porous carbonaceous material derived from biomass, into cement-based materials. Biochar, a porous carbonaceous material derived from thermochemical conversion of biomass has emerged as a technology for carbon dioxide (CO_2) capture and sequestration and has gained prominence as a crucial alternative in combating climate change, recognized by the IPCC since 2018. Biochar's effectiveness in carbon dioxide (CO_2) capture stems from a combination of physical adsorption and chemisorption processes, which are enhanced by optimizing its pore structure, surface chemistry, and mineral content. When incorporated into cement-based materials, biochar acts as a partial replacement for cement or aggregates, offering benefits such as increased mechanical strength, enhanced durability, and improved hydration. Carbonic curing, mineralization or enforced carbonation are expressions being used when CO_2 reacts with Portland cement materials at an early age to convert $Ca(OH)_2$ into stable $CaCO_3$, boosting the material's final strength and durability. Biochar's inherent properties, such as its high porosity and specific surface area, make it an excellent internal curing agent and facilitate CO_2 diffusion within the matrix. The aim of this article is to present, based on some articles published from the last 5 years, a compilation of key factors that influence the CO_2 uptake of cement-based materials at early ages with biochar. Some of these factors are the biomass source, pyrolysis temperature, particle size and humidity control (internal and external). While biochar can function as a "filler" or exhibit pozzolanic activity, its interaction with cement and other supplementary cementitious materials (SCMs) require consideration, as high dosages can reduce overall CO_2 capture capacity. Furthermore, chemical and physical modifications can increase the capacity of biochar's CO_2 adsorption in cement-based applications.

Keywords: Biochar, Carbon Uptake, Mineralization, SCM, Cement-Based Materials

See Full Paper in the Proceedings.

INFLUENCE OF CARBONATION TIME ON REACTIVE MAGNESIA OXIDE SLURRY AND ITS PERFORMANCE IN BLENDED PORTLAND CEMENT

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Abstract

This study investigates the first 90 min of aqueous carbonation (99% purity CO_2) of reactive magnesia oxide (MgO) at a water-to-solid ratio of 1.67 under ambient conditions. Results show that brucite is the primary mineral consumed within the first 10 min of carbonation, while the nesquehonite appears at 40 min and becomes the dominant phase after 90 min. Introducing ordinary Portland cement (OPC) to the carbonated MgO slurry (RMC) under ambient mixing conditions promotes the formation of abundant nano-$CaCO_3$ particles that coat the surfaces of nesquehonite, providing nucleation sites that enhance cement hydration. At 1 day, both vaterite and calcite are observed in the RMC-OPC paste, and the formation of rich calcite and monocarboaluminate contributes to a denser microstructure and increased mechanical strength. As a result, the 28-day compressive strength of the RMC-OPC paste is approximately twice that of the uncarbonated MgO slurry with OPC paste.

Keywords: Reactive magnesia oxide, Nesquehonite, Aqueous carbonation, Nano-$CaCO_3$, Compressive strength

Investigating the Impact of Floor Coverings on Concrete Carbonation in Residential Buildings

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Abstract:

Concrete carbonation is a key process driving long-term CO_2 uptake in the built environment. However, for internal surfaces the rate of uptake can vary depending on the location and exposure condition of the concrete surfaces. In residential buildings, floor coverings such as tiles or carpets may act as physical barriers that reduce CO_2 diffusion and limit carbonation depth, with the potential effect not well captured in current life cycle assessment practices. This study investigates the influence of coverings on carbonation in concrete floors for both low-rise and mid to high-rise residential buildings over a lifetime of 50 years. A numerical simulation approach was applied using established carbonation models. Surface conditions considered include bare concrete, tiled surfaces, and carpeted floors. The research seeks to improve the accuracy of CO_2 uptake estimates in residential buildings by clarifying the role of floor finishes in carbonation modelling. The results showed that in the low-rise structures external walls dominated and the impact of coverings was minor (3%). In mid-to-high-rise structures slabs dominated uptake, with the reduction of approximately 12%.

Keywords: concrete carbonation; residential buildings; CO_2 uptake; building modelling

See full Paper in the Proceedings

NANO- AND MICRO-CHARACTERISATION ON THE HETEROGENEITY OF ITZS IN RECYCLED LUMP CONCRETE

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Abstract

Recycled lump concrete (RLC) is a new sustainable construction material for filling large-sized demolished concrete lump (DCL) piles with fresh mortar or concrete. Due to the differences from conventional concrete casting technology, the heterogeneity and cohesion performance of the interfacial transition zones (ITZs) require further investigation. In this study, two types of self-compacting mortar (SCPM) were designed using blends of cement, recycled sand/recycled powder (RS/RP), and fly ash as raw materials. The filling performance of the SCPM was evaluated based on the microstructure, micromechanical properties and phase distribution within the ITZs and the adjacent matrix surrounding DCLs. Both types of SCPM effectively fill the gaps between DCLs, observed in the appearance of specimens. However, the bonding strength of bottom and oblique bottom ITZs of RLC prepared by SCPM without fly ash and superplasticizer was poor, making it impossible to produce ITZ samples from these two locations successfully. The heterogeneity and cohesion strength of the ITZs surrounding the DCLs depends on the distribution of pores and grains. Grains, including RP and fly ash, accumulated at the top and oblique top sides of the DCL due to sedimentation. Fly ash and RP effectively promoted the healing of micro-pores and cracks around DCLs but had a limited effect on pores and cracks with an average equivalent diameter greater than 1 μm. In summary, the ITZs at the top and oblique top sides of the DCLs had a denser microstructure and better bonding performance than those at other locations around the DCLs.

Keywords: Recycled lump concrete; Recycled sand/recycled powder blends; Interfacial transition zone; Heterogeneity; Microscopic characterization

ACCELERATED CARBONATION OF ALKALI ACTIVATED BINDERS OBTAINED BY DIFFERENT BYPRODUCTS

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Abstract

Alkali activated materials (AAMs) and geopolymers are a promising route to reduce greenhouse gas emissions related to the cement industry and its use. They generally show engineering properties, such as excellent mechanical and fire performances, and high temperature and acid resistance. AAMs are also involved in carbonation processes when exposed to atmosphere: activator solutions can release Na^+ ions that can be quickly carbonated, if they are not involved in the gel formation; moreover, some calcium-rich precursors lead to the formation of CH and CSH gels which can be further carbonated.

A quantification of carbonation for AAMs has not been extensively carried out yet. Therefore, this abstract aims at understanding whether the carbonation processes occurring in AAMs can be considered attractive in terms of their potential as CO_2 absorbers. Various AAMs were prepared based on a blend of metakaolin (MTK) and ceramic waste (CW) from the grinding process of porcelain stoneware tile or wood biomass ash (WBA) sourced from a thermoelectric power plant, fuelled by poplar wood chips. A constant MTK replacement content of 30 wt% was considered and precursors were activated by both sodium hydroxide and sodium silicate solutions. After a sealed curing of 2, 7 and 28 days, an accelerated carbonation exposure (CO_2% = 4%, T=20 °C and RH=70%) was performed for 3, 7 and 28 days. Modifications in microstructure and compressive strength were assessed after accelerated carbonation. An increase in carbonation depth was observed with carbonation exposure up to 28 days. Samples with CW and WBA exhibited deeper carbonation when carbonated after 2 days of curing, due to a larger available Na^+ in pore solutions. No changes in compressive strength were observed in carbonated samples, thus indicating that engineering performance of the binders were preserved even after the carbonation process.

Acknowledgements: Project REWINDS "REcycling of Waste Into New Demonstrated Sustainable Solutions" funded by Emilia Romagna ERDF Programme 2021-2027 is gratefully acknowledged.

Keywords: alkali activation, wood biomass ash, ceramic waste, metakaolin, carbon uptake

Study on Evaluation Method and Criteria for Carbonation Suppression Effect of Exterior Finishing Material

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Abstract. In this study, we examined the evaluation method and evaluation criteria for evaluating the carbonation suppression effect of finishing materials used for the exterior of reinforced concrete buildings. We proposed a test method for carbon dioxide transmission rate of finishing materials and clarified the relationship with the carbonation ratio by the accelerated carbonation test while 52 weeks. In addition, the value of the carbonation ratio by previous studies, we proposed a criteria for the carbonation suppression effect in consideration of the deterioration of the finishing material.

Keywords: Concrete, Carbonation, Finishing materials, Carbonation ratio, Carbon dioxide transmission rate

See Full Paper in the Proceedings.

CO_2 UPTAKE CAPACITY OF WOOD BIOMASS ASH BASED MORTARS

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Abstract

Supplementary cementitious materials (SCM) are largely adopted in cement industry to decrease the clinker content and obtain more sustainable cements. A great interest has been specifically addressed to SCM rich in amorphous silica and/or alumino-silicate thus promoting pozzolanic reactions with the portlandite formed during the hydration of clinker. Recently, the need to further reduce carbon dioxide emissions and the environmental footprint of the cement industry, is promoting the selection of SCM also able to work as CO_2 absorber. This contribution is addressed in this direction, exploiting wood biomass ash (WBA) sourced from a thermoelectric power plant, fuelled by poplar wood chips. The characterization of WBA shows an average size of 14 mm, a content of portlandite (≈ 25 wt%) and amorphous phases, and a chemical composition rich in Al_2O_3 and SiO_2. These characteristics make WBA particularly interesting as SCM, potentially capable to work as CO_2 absorber and promoter of pozzolan reactions. Mortars samples, in which WBA replaced 0, 25 and 50% w/w of CEM I 52.5 R used as binder, have been prepared and cured for 28 days at 20 °C and R.H. >90%. After this traditional curing, an accelerated carbonation was carried out for 1, 3 and 7 days at 20 °C, 10% CO_2 and R.H.=70%. A first quantification of CO_2 absorption has been estimated by thermogravimetric analysis and microstructural characterizations by MIP and BET are ongoing to evaluate pore size refinement. First results show that CO_2 uptake is about 11 and 13% after 7 days of accelerated carbonation for mortar samples containing 25 and 50% WBA as cement replacement. As carbonation is also influenced by curing time, the obtained data will be also compared with similar samples cured for 7 days in standard conditions (i.e. 20 °C and R.H. >90%) and subjected to the same accelerated carbonation process.

Acknowledgements: Project REWINDS "REcycling of Waste into New Demonstrated Sustainable Solutions" funded by Emilia Romagna ERDF Programme 2021-2027 is gratefully acknowledged.

Keywords: SCM, wood biomass ash, CO2 uptake, microstructure, carbonation.

EVALUATION OF COATING EFFECT REDUCTION TO SUPPRESS CONCRETE CARBONATION BASED ON FIELD SURVEY

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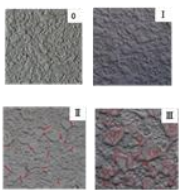
Abstract

Authors propose a method to predict deterioration of exterior finishes using Markov chain model, shown in Fig.1, based on field survey of existing RC buildings (Table.1). Authors defined accumulated exceeded degradation (AED) based on Markov chain curvature shown in Fig.2. Correlation between AED of finishing and carbonation progress of concrete was confirmed. Based on this finding, authors evaluate concrete carbonation progress with degradation of finishing, as shown in right side of Fig.2. In this case, effective time of CO_2 ingress suppression by finishing was estimated to be around 20 years. By using this approach, it might be possible to estimate service life of RC buildings with surface coating in terms of concrete carbonation. That means, in opposite, that capacity of CO_2 uptake of concrete with surface coating can be estimated.

Keywords: Surface coating, Visual inspection, Markov chain model, Carbonation progress.

Table 1. Surveyed Buildings.

	Survey Buildings			
	A	B	C	D
Construction	reinforced concrete construction			
Stories	4	4	4	12
Design Strength	18 N/mm²	18 N/mm²	21 N/mm²	21 N/mm²
Year of construction	1978	1977	1977	1977
Year of Repaint	2010	2008	2001	1997
Age from Repaint	6 old	8 old	15 old	19 old
Coating Material (construction)	Multi-layer Coating Material (E Type)			
Coating Material (repaint)	Synthetic Resin Emulsion Paint			
Color of finish	white			



(range 50mm×50mm)
Grade O : No crack
Grade I : A few cracks
Grade II : About 10 cracks
Grade III : Mesh type cracks overall

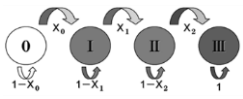
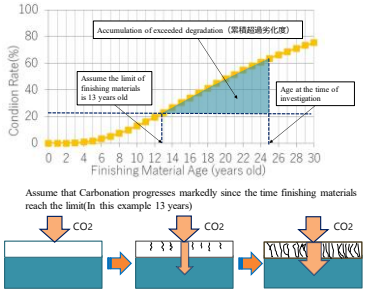
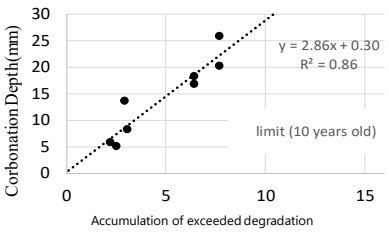


Table 2. Degradation Probability.

	x0	x1	x2
Max	0.384	0.396	0.400
Min	0.016	0.015	0.004
Average	0.108	0.116	0.178

Figure 1. Degradation of finishing and probability of progress in Markov Chain Model





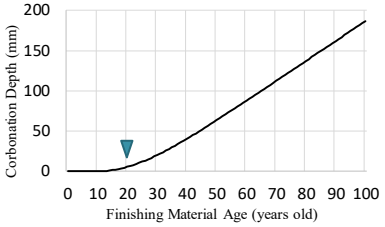


Figure 2. Degradation of finishing and its relation to carbonation progress

THERMODYNAMIC-CALCULATIONS BASED REACTIVE-TRANSPORT MODELING TO STUDY CARBONATION IN LOW-CARBON CONCRETE

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Abstract

As various types of alternative supplementary cementitious materials (SCM) are emerging, there is increased focus on predicting durability performance of concretes produced with low-clinker blended binders. While the synergetic reactions among clinker, limestone and SCM could provide significant benefits to concrete by reducing porosity, pore connectivity and transport coefficients, hence improving various mechanical and durability properties, they can also make concrete more vulnerable to other durability problems such as carbonation, reinforcement corrosion, and alkali-aggregate reaction. Some of the factors that can be negatively affected in low-clinker systems comprise the chemistry of the pore solution including its pH, alkali content, and electrical resistivity; hydrated phase composition, including C-(A)-S-H content and types and calcium hydroxide content; pH buffer capacity; chemical and physical binding of alkalis and chloride. Considering the variability associated with the chemical composition and reactivity of the cementitious materials, prediction of durability performance of these low-carbon systems is a challenging task. We present a thermodynamic calculations-based approach to predict carbonation of such systems. The model uses thermodynamic/kinetic calculations to predict key durability performance indicators such as electrical resistivity, transport properties, porosity, and strength as the low-carbon concrete experiences internally- or externally- induced deteriorative processes. In this approach thermodynamic/kinetic calculations are fully coupled with the numerical solution of transport equations. The only inputs to the developed approach involve the chemical composition and reactivity of the cementitious materials and the mixture proportions; therefore, the coupled modelling approach provides a generic framework to simulate a wide-range of cementitious systems without time-consuming and error-prone tests to determine key input material properties. In this presentation, firstly, the principles of the thermodynamic calculations-based modelling approach will be presented. Then, we will demonstrate several examples of durability performance predictions of low-carbon concrete using the developed framework.

Keywords: thermodynamic modeling; reactive-transport modeling; SCM; carbonation; pozzolanic reactivity; limestone

THE INFLUENCE OF KEY PARAMETERS IN MODELING AT-SCALE CO_2 UPTAKE IN CEMENT-BASED MATERIALS

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Abstract

The greenhouse gas emissions (GHG) associated with cement and concrete must rapidly decrease to meet Intergovernmental Panel on Climate change (IPCC) targets to limit the rise of global temperature and mitigate the climate crisis. To contribute to GHG reduction efforts, carbon dioxide (CO_2) uptake throughout the service and end of life (EoL) of cement-based materials has garnered increased attention as a previously unaccounted for and low-cost pathway to fix a large amount of CO_2 for long periods of time. Recent estimates of carbonation have been incorporated into cement and concrete production roadmaps to achieve net-zero GHG emission. Notably, many regional or industrial-level estimates of CO_2 uptake by cement-based materials share common methodologies, assumptions, and modelling parameters; a variant of these modelling approaches is also proposed in the current EN 16757 standard. With current estimates at times hinging on a series of singular (though expert selected) values, this work seeks to investigate the degree to which specific parameters influence the resulting CO_2 uptake amounts. Herein, key modelling parameters (including time, CaO content, degree of carbonation, carbonation coefficients during different life stages, amount and type of supplemental cementitious materials) are investigated *via* a sensitivity analysis. The influence of these parameters on the estimated CO_2 uptake is analysed. The results demonstrate that a reliable total CO_2 uptake strongly depends on considerable uptake occurring during the demolition and secondary-life stages, and they indicate that an optimum SCM fraction exists regarding CO_2 uptake during use stage. Together this work identifies controlling parameters in existing modelling efforts which need to be carefully selected for accurate carbonation estimates. This work highlights the need for robust, science-informed guidelines for estimating the CO_2 uptake by cement-based materials to ensure well-calibrated modelling of the GHG impacts associated with building materials.

Keywords: carbon uptake, carbonation, modelling, sensitivity, key parameters

MECHANISTIC INSIGHTS INTO THE ENFORCED CARBONATION BEHAVIOR OF ALUMINATE PHASES IN CEMENT CLINKER

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Abstract

The study elucidates the carbonation behavior and mechanisms of aluminate phases—ferrite (C4AF) and tricalcium aluminate (C_3A)—in cement clinker under enforced wet carbonation. Both phases exhibit thermodynamically spontaneous carbonation, with their reaction kinetics and phase assemblages strongly influenced by solution pH. For C_4AF, carbonation initiates with hemi-/monocarbonate formation, progressing to generate calcite (Cc), amorphous $Al(OH)_3$, and $Fe(OH)_3$. A distinctive core–shell structure forms, comprising a Cc-rich core and an iron-bearing $Al(OH)_3$ outer layer. High initial pH significantly enhances ferrite dissolution and CO_2 solubility, increasing $Al(OH)_4^-$ concentration, prolonging monocarbonate oversaturation, and promoting Cc and $Al(OH)_3$ precipitation. In contrast, C_3A carbonation is highly pH-sensitive within the range of 5.8–12.5. Below pH 11.0, Cc becomes the dominant product, with the highest carbonation efficiency observed at pH 9.5–10.0, where only 4.1 wt% of unreacted C_3A remains after 10 minutes. At pH >11.0, CO_3^{2-}-AFm phases dominate. The carbonation pathway is governed by three pH-dependent effects: (i) pH modulates Al dissolution and the Ca/Al ratio, altering the supersaturation states of Cc and AFm; (ii) it affects $Al(OH)_3$ precipitation thresholds, allowing $Al(OH)_4^-$ to react with Cc and form AFm; and (iii) under acidic conditions (pH < 6), an amorphous Al-rich layer forms rapidly, inhibiting further reaction. Together, these findings provide comprehensive insights into the role of pH in controlling aluminate carbonation mechanisms and products, offering guidance for optimizing CO_2 uptake and stability in cementitious materials.

Keywords: carbonation, clinker, aluminate, carbonation mechanism, carbonation kinetics

QUANTIFYING THE EFFECT OF RAINFALL ON THE STEEL CORROSION RATE IN CARBONATED CONCRETE WITH HYGROSCOPIC PROPERTIES.

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Abstract
Standards, based on field and lab experience, exist to design durable concrete exposed to indoor, sheltered or non-sheltered conditions. However, no property based engineering tools quantify the effect of real wetting and drying cycles on the rebar corrosion rate.

The deployment of the forthcoming new generation of low-carbon materials should happen with no compromise on their durability, in particular carbonation-initiated rebar corrosion. The CO2 buffering capacity does decrease with clinker content and the increase of concrete carbonation rate with W/CaO [1] remains a challenge for low CO2 concrete design. Therefore, one avenue is the quantification of rebar corrosion rate to ensure 50 y service life. Experimental evidence yields a dependence of corrosion rate to concrete resistivity [2], which in turns depends on water content in the pore space [3], at water equilibrium. Here, we analyze the rebar corrosion during transient water mass transfer relevant for variable climatic conditions.

One low CO2 concrete is characterized in terms of basic hygroscopic properties and corrosion rates in wet and dry conditions. Using this data, water content profiles within an 18 cm wall are predicted with WUFI [4] after reaching steady state cycles for different wetting and drying periods and time of wetness. Using local water content, rebar corrosion rates are calculated for different cover depth.

Results confirm the already known role of concrete cover to limit the effect of wetting on average corrosion rates. In addition, the existence of water content gradient leads to corrosion rate distribution along the circumference of the rebar. If the cycle average of corrosion rate remains close whatever the position along the circumference, the amplitude between extremum values of rates does depend on cover depth and climatic conditions. Eventually, a corrosion risk map based on climatic conditions and rebar cover depth is given.

Keywords: Corrosion; Concrete; Hygroscopic Properties; Cycles; Numerical Model

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Micro-structured design of binder-based absorbers for carbon dioxide (CO2) uptakes

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Abstract. This work introduces the key aspects to optimize binder-based microstructures using machine learning techniques, with the primary goal of enhancing their uptake properties, particularly the capacity to absorb carbon dioxide (CO_2). The utilization of CO_2 in concrete and its components is currently achieved by converting gaseous CO_2 into solids (carbonates) through a process known as mineral carbonation. To bind CO_2 in solids as carbonates, two essential components are required: i) a supply of cations to form solid carbonate minerals, and ii) a supply of alkalinity that enables the rapid conversion of CO_2 into carbonate ions. The most common carbonate formed is calcium carbonate (CaCO3), where calcium serves as the cation. Alternatively, systems rich in magnesia also show potential for CO_2 curing, resulting in the formation of hydroxy-magnesites and/or other magnesium-carbonate hydrates. The proposed approach encompasses several key numerical steps to design a micro-structured concrete absorber based on machine-learning procedures, such as data collection and model training, rendering microstructural variables compatible with machine-learning algorithms, selection of appropriate machine-learning algorithms, model validation, optimization, and prediction. By enabling the exploration of a vast range of microstructures and mineral carbonation processes, this approach offers an avenue to engineer concrete materials with superior CO_2 absorption capacities, contributing to the creation of sustainable and environmentally friendly construction materials. The synergy between machine learning and concrete science has the potential to revolutionize the construction industry's approach to enhancing properties while minimizing environmental impact.

Keywords: CO2 Uptake; Concrete; Machine Learning; LCA; Carbonation.

See full paper in the proceedings.

Carbonation Profiling of Metakaolin Blended Cements by ^{1}H-NMR relaxometry

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Abstract. Carbonation profiling of cementitious materials is traditionally based on the phenolphthalein test, which often underestimates actual carbonation depth and provides limited insight into moisture redistribution and pore structure evolution. In this study, proton nuclear magnetic resonance relaxometry (^{1}H-NMR) was employed as the principal tool to establish a comprehensive carbonation profile of white Portland cement (WPC) and metakaolin-blended cement with a water-to-binder ratio of 0.5 and exposed to accelerated conditions with a CO_2 concentration of 3%. Using hydrogen nuclei in water as probes, ^{1}H-NMR enabled direct quantification of water content and allowed quantitative characterisation of pore structure evolution. Combined with thermogravimetric analysis (TGA), a more precise determination of the carbonation progress can be made. Results show that carbonation induces depletion of mobile water and a reduction in total pore volume. These findings demonstrate that ^{1}H-NMR is a powerful tool for studying the water redistribution and microstructural evolution during carbonation.

Keywords: Cementitious Materials, Durability, Carbonation, Microstructure, ^{1}H-NMR relaxometry.

See full paper in the proceedings.

INFLUENCE OF AQUEOUS AND DRY CARBONATION SET-UP ON THE CO_2 SEQUESTRATION OF LADLE SLAG AND BIOMASS-ASH

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The growing need to address climate change has sparked interest in carbon capture and storage (CCS) technologies. Mineral carbonation is of particular interest due to its potential for permanently sequestering CO_2. This study investigates how two carbonation methods — aqueous and dry — influence the CO_2 sequestration capacity of two industrial by-products: ladle slag (LS) and biomass ash (BA), respectively. Rich in calcium and magnesium, these materials are promising feedstocks for mineral carbonation thanks to their high alkalinity and reactivity. Experiments were conducted under controlled laboratory conditions to assess the carbonation efficiency, mineralogical transformation and CO_2 uptake of LS and BA in aqueous and dry setups. Aqueous carbonation was carried out using water slurry systems under elevated CO_2 pressure at room temperature, while dry carbonation involved exposing the solid materials to humidified CO_2 gas in the absence of liquid water. Parameters such as reaction time, temperature, particle size and the solid-to-liquid ratio (in the case of the aqueous tests) were optimized for comparative analysis.

The results revealed a significant CO_2 uptake in both materials attributed to an enhanced mass transfer and dissolution-precipitation mechanisms that promote carbonate formation. Thermogravimetric analysis (TGA) revealed the increase of CO_2 from 19 wt.% and 16 wt% up to 28 wt.% and 23 wt.% for LS and BS, respectively. SEM analysis indicated the formation of different carbonate polymorph phases with different carbonation set-ups, especially in the case of BA. Attenuated Total Reflection–Fourier Transform Infrared (ATR-FTIR) spectroscopy and mineralogical analysis using X-ray diffraction (XRD) confirmed this. Utilizing non-carbonated and carbonated waste in alkali-activated materials was proven by producing binary binders with metakaolin and testing their compressive strength development over 28 days. The results demonstrate the potential for utilizing carbonation not only for CO_2 sequestration, but also for reusing carbonated waste as binder precursor compounds by applying alkali activation technology.

Keywords: Carbonation sequestration, Mineral waste, Slag, Bioash, Alkali-activated materials

Energy-Efficient Synthesis of Alkali Activated Sintered Lightweight fly ash-based Aggregates under Flue Gas Carbonation

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Abstract

The depletion of natural aggregates and the environmental consequences of mining have motivated the construction industry to explore sustainable alternatives such as Lightweight aggregates (LWAs). Fly ash (FA), abundantly generated in Indian thermal power plants, provides a viable feedstock for producing lightweight aggregates (LWAs). This study focuses on developing alkali-activated FA-based LWAs at a reduced sintering temperature (~950 °C for 24 h) and enhancing their carbon sequestration potential through accelerated carbonation using CO_2 (15% CO_2 at 5 h) and simulated flue gas (24% CO_2, 75.80% N_2, 0.08% SO_2, and 0.12% NO_2).

Class F fly ashes from Raichur thermal power plant and NTPC power plant (Batch I and II) were characterized through XRF, XRD, SEM–EDS, and isothermal calorimetry. Batch II FA demonstrated higher reactivity (~210 J/g) compared to Batch I, attributed to a greater amorphous silica fraction. LWAs were synthesized by varying the activator (sodium hydroxide, NaOH) molarity (2M and 4M) and excavated soil content (0 – 20%) and lime content (0-10%). Single aggregate crushing tests showed that mixes with 20% soil and 2M NaOH (designated as 2FK20) achieved the highest strength among Raichur FA aggregates (3.78 ± 0.45 MPa under CO_2 curing). Lime impregnation followed by CO_2/flue gas curing improved carbonate mineralization, contributing to strength gain. However, lime blending during dry-mixing (pre-sintering) induced thermal cracking, indicating that post-sintering impregnation is more effective.

For NTPC fly ashes, significant performance differences were observed. Batch I (2DK20) under CO_2 curing achieved 3.88 ± 1.12 MPa, while Batch II (4WK20) reached the highest overall strength (5.26 ± 0.64 MPa) under flue gas curing. Statistical analysis confirmed that reactivity and pore structure strongly influenced strength outcomes. BET analysis revealed that higher surface area and accessible pore volume facilitated CO_2 diffusion and Ca^{2+} migration, enhancing carbonate precipitation.

Thermogravimetric analysis indicated CO_2 uptake capacities up to 1.34% by weight (~12.5 kg CO_2 per ton of LWA). Compared with literature, the synthesized LWAs demonstrated superior mechanical performance at lower sintering energy demands, achieving ~5.5 MPa strength at 950 °C, outperforming studies conducted at higher temperatures (≥1080 °C).

Overall, the research highlights that optimized alkali activation, soil blending, and lime-assisted post-sintering treatments enable the synthesis of mechanically robust, low-energy LWAs with carbon sequestration potential. These findings establish a novel pathway for producing sustainable aggregates that contribute to India's 2070 decarbonization targets.

Keywords: Carbon Sequestration, Light weight aggregates, Flue gas carbonation, Sustainable Synthesis, Fly ash

HOW CARBONATION ALTERS THE MICROSTRUCTURE AND MOISTURE TRANSPORT IN CONCRETE?

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Abstract

Carbonation, the chemical reaction between CO_2 and hydrated cement, fundamentally reshapes the microstructure of cementitious materials, leading to significant alterations in moisture transport. The most significant change is that the precipitation of carbonation products, mainly calcium carbonate, can effectively fill and block pores, which leads to a remarked decrease in total porosity. However, the effects of carbonation on the pore size distributions reported in different studies can be either pore coarsening or pore refining, which may depend on the types of binders. Consequently, the measured moisture transport coefficients (permeability, sorptivity, and vapor diffusion coefficient) increase with pore coarsening or decrease with pore defining.

After reviewing the relevant studies in the literature, we identify two key mechanisms controlling the alterations of the pore structures by carbonation: pore structure refinement due to the precipitation of calcium carbonate and microcracking generated by carbonation shrinkage. At the early stage of carbonation, with the diffusion of CO_2 and reactions with hydration products mainly portlandite, calcium carbonate precipitates in the pores that are filled with water and thus results in the pore clogging, meaning these pores cannot be detected in the pore structure measurements. With the progress of carbonation, if C-S-H gels heavily react with CO_2, it will result in a net reduction in the volume of the solid phases, together with the evaporation of water generated during carbonation reactions, causing the cement paste to shrink and further inducing microcracks. The competition between pore clogging and microcracking is not universal and depends on the properties of concrete (quality, binder types) and the exposure conditions (relative humidity, CO_2 concentration). By well controlling these factors, we would be able to refine the pore structure and to enhance the durability of carbonated concrete.

Keywords: moisture transport, carbonation, microstructure, low-carbon cement, pore structure refinement, carbonation microcracks

The concept of Degree of Carbonation and experimental evidence

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Abstract. Cement manufacture is contributing to CO_2 emissions as calculated by the Intergovernmental Panel for Climatic Change (IPCC) of 520 kg of CO_2 per tonne of clinker. When the concrete is produced, hydrated cement phases in concrete absorb CO_2 through the carbonation of cement paste. The uptake of CO_2 with respect to the CaO content in the cement is named as degree of carbonation, DoC. The calculation of that DoC or "recarbonation" of concrete has been assumed as a fixed percentage in most of the studies that were undertaken in the past for calculating the carbon footprint. However, the DoC may vary with the cement type, the concrete mix proportion and the particular exposure class. These values of DoC were calibrated in a Spanish study with 15 different cements, 4 concrete mix proportions and 3 exposure classes. Present paper comments on the concept of DoC and summarizes the experimental work made in Spain. The statistical analysis of the results indicated an average value of the degree of carbonation (DoC) for all cement types, except those containing high proportions of GGBS, of around DoC = 50%. This value is different from some recommended in the Annex BB of standard EN 16757 for the European Environmental Declarations.

Keywords: Carbonation, recarbonation, cement-type, concrete-mix, exposure-class, standars.

See full paper in the proceedings.

OPTIMIZING CO2 CONVERSION EFFICIENCY IN RECLAIMED CONCRETE WATER THROUGH MINERAL CARBONATION AND PH-DRIVEN PROCESS MONITORING

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Abstract

Reclaimed water (RW) from the ready-mixed concrete industry is a high-alkalinity waste product whose reuse is hindered by quality variability, leading to poor concrete performance, including reduced early strength and workability. This study investigates CO_2 treatment as a approach to neutralize RW and sequester CO_2 by transforming dissolved carbonate ions into stable solids via mineral carbonation. Artificial RW (2.5%, 5%, 10% solid content) was treated in a column reactor with injected CO_2 concentrations ranging from 0% to 100%. Results demonstrated that CO_2 injection effectively neutralizes the high-alkaline water, causing a rapid, near-linear decrease in pH. This neutralization process concurrently generates new solid particles , which TGA analysis confirmed to be primarily calcium carbonate ($CaCO_3$). Critically, the highest CO_2 conversion efficiency was not achieved at the highest (100%) CO_2 concentration, which proved significantly less efficient , but at an optimized injected CO_2 level of approximately 20%. This finding is essential for the economic viability of the technology. Furthermore, a strong linear relationship was identified between the drop in pH and the amount of $CaCO_3$ formed during the active reaction phase (down to pH 7). This confirms that simple pH measurement can be employed as a reliable, in-situ proxy for real-time process control and monitoring of the carbonation progress.

Keywords: Reclaimed Water, CO2 treatment, Mineral Carbonation, pH Neutralization, CCUS

The fate of heavy metals in recycled cement pastes upon enforced carbonation

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Abstract

The valorization of construction and demolition waste (CDW) has become a central strategy in advancing sustainability within the construction sector. Recycled concrete paste (RCP), derived from the fine fraction of demolished concrete, has recently attracted attention as a reactive source material for carbon capture and utilization. Through enforced carbonation-an engineered mineral carbonation process-RCP can be transformed into a carbonated recycled concrete paste (cRCP) consisting mainly of stable calcium carbonate ($CaCO_3$) and amorphous aluminosilicate gel (Al-Si gels). This reaction permanently stores CO_2 while generating a reactive pozzolanic material that can partially replace clinker in cement, thus offering significant carbon reduction potential across the cement value chain.

The growing interest in RCP carbonation highlights its potential as a pathway toward sustainable concrete technologies. To fully realize this environmental benefit, it is essential to improve our understanding of how the process interacts with trace elements, particularly in recycled materials that, although generally containing very low levels of such elements as shown in previous assessments, may occasionally contain small amounts due to contamination. The aqueous conditions and evolving pH during enforced carbonation can significantly influence the speciation and mobility of these elements, ultimately affecting their long-term stability. Advancing knowledge in this area will help ensure that carbonation strategies not only enhance material performance but also maintain environmental safety and integrity.

Our study investigates the chemical and mineralogical evolution of heavy metals during enforced carbonation of RCP, with a focus on their partitioning between solid and aqueous phases. The results provide new insights into the mechanisms governing metal retention in carbonated cementitious matrices and demonstrate that enforced carbonation achieves CO_2 sequestration and may also contribute to the retention of certain heavy metals. These findings highlight the potential for integrating waste valorization and carbon capture within a single circular process in an environmentally sustainable manner.

Keywords

Mineral carbonation, CO_2, recycling, sorption, precipitation, calcite

Carbon cured cementitious materials as a solution for Urban Heat Island mitigation

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Abstract.
Achieving sustainable cities requires materials that move beyond conventional carbon reduction, offering solutions to escalating urban heat and energy demands. This work examines two distinct pathways for developing carbon-negative infrastructure using waste-derived cementitious systems. One strategy centers on alkali-activated steel slag pressed blocks, leveraging ambient carbonation to create composites that efficiently capture CO_2, exhibit enhanced solar reflectivity, and possess robust, durable microstructures—attributes enabled by synergistic carbonation and pozzolanic reactions. The second approach introduces carbonated aggregates sourced from food industry by-products, such as periwinkle shell powder, which are embedded into cementitious matrices to boost mineralization and radiative cooling in carbon-cured materials. Both approaches repurpose industrial waste to deliver sustainable, next-generation building materials while addressing both embodied and operational carbon challenges. Performance results demonstrate that these systems can achieve significant passive cooling in urban environments, with pavements and roofs registering up to 16 °C lower surface temperatures under peak solar loading compared to conventional solutions. Collectively, they offer scalable pathways to improved energy efficiency and public health within the evolving landscape of modern infrastructure.

Keywords: Urban heat island mitigation, CO_2 sequestration, Carbonated aggregates, Alkali-activated steel slag.

See full paper in the proceedings.



RECENT DEVELOPMENTS IN DATA AND META-DATA MANAGEMENT

3D Printable Sustainable Binders Containing Indigenous Materials with Organic Additives: Rheological, Mechanical Characteristics and Life Cycle Assessment

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Abstract

The global construction sector is shifting towards sustainability as concerns grow over the environmental burden of Portland cement. Ancient systems using lime and mud offer proven durability with significantly lower emissions. 3-dimensional(3D) printing presents a transformative opportunity to revive these materials, but challenges persist in adapting their rheology and structural performance for digital construction. This study proposes a novel blend of indigenous materials (lime, mud) and industrial waste, fly ash, modified with organic additives (rice-starch, jaggery, and myrobalan) to formulate an extrusion-friendly, high-performance composite for 3D printable ink. Morphological and elemental characteristics of the raw materials were examined using Field Emission Scanning Electron Microscope (FESEM) and Energy Dispersive X-ray Spectroscopy (EDS), supplemented by evaluation of their physical properties. Printable ink proportions (Plain, binary and ternary) were developed and evaluated for rheological and mechanical performance. Rheological behaviour was analysed via rotational rheometry, hydration kinetics through isothermal calorimetry. Extrudability was investigated through flowability, yield stress development and open time, followed by printability through layer width, continuity and layer height. Then, buildability was evaluated by layers' total build height and shape retention tests, followed by assessments of compressive strength, ultrasonic pulse velocity (UPV), water absorption. Further, these findings are validated by FESEM and EDS and Fourier Transform Infrared Spectroscopy (FTIR) analysis. Finally, Life Cycle Assessment (LCA) was conducted using the ReCiPe Midpoint (H) method. Ternary printable ink(starch+Jaggery+Herada) (TPI) showed greater than 140% increase in yield stress over 105 min, maintaining required flowability, a key for buildability. Isothermal calorimetry revealed 24% higher cumulative heat release, indicating accelerated yet controlled hydration. The buildability of TPI achieved a buildability index (BI) of 0.98 for 15 printed layers and a shape retention factor (SRF) of 99.5%, which is 11.3% higher than that of plain printable ink (PPI). Mechanical testing showed an increase of 39% in compressive strength and improved UPV and thermal properties, supported by denser microstructure and enhanced pozzolanic reactions compared to plain ink. LCA results showed up to 50% reduction in Global warming potential (GWP100) CO_2-eq emissions and energy demand compared to Ordinary Portland Cement (OPC) Ink. The study demonstrates a viable pathway to integrate indigenous materials with modern 3D printing technology, offering a sustainable, structurally sound solution that preserves traditional architectural identity and historical relevance.

Keywords: 3D Concrete Printing, Indigenous Construction Materials, Rheology, Life Cycle Assessment (LCA), Organic Additives

See full Paper in the Proceedings

FROM LAB DATA TOWARDS MACHINE-LEARNING: MANAGING DATA IN INTERNATIONALS PROJECTS

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Abstract

Effective and structured data management is critical for enabling data reuse, meeting funding requirements, and supporting the growing integration of AI and simulation in materials science. These challenges are amplified in international research collaborations, where consistent documentation, data accessibility, and standardization across institutions and cultures can be difficult to achieve. We address these issues through our lab's data management system based on eLabFTW, an open-source electronic lab notebook (ELN) and database solution, developed and applied within the international research project Ecopave. This project focuses on sustainable pavement technologies and involves German and Indian partners from both academia and industry.

Our implementation introduces a clearly structured data model that organizes entries into two core categories: Resources and Experiments. Resources include both raw materials and experimental procedures. Raw material entries contain detailed information regarding its source. Experimental procedure entries provide comprehensive descriptions of how experiments are conducted, ensuring clarity and reproducibility, which is especially useful in international research projects. Experiments, on the other hand, document raw material properties, specific mix designs, and test results. Each Experiment links not only to the relevant Resources but also to its associated Experiments, creating a connected workflow. Associated Experiments could be for instance an entry for processed materials (e.g., ground or heat-treated samples), which is helpful to compare results keeping the primary raw material in mind.

The system allows users to follow the status of experiments, offering a clear overview of the project's overall progress. This structure enables consistency, traceability, and cross-project comparability, which are especially vital in distributed, multi-partner settings. By capturing experimental workflows and outcomes in a standardized, structured format, we reduce administrative burden and facilitate seamless collaboration. To ensure that all entries are stored in a machine-readable format, we make use of dedicated templates for both Resources and Experiments. Furthermore, a Python interface enables flexible filtering and querying, which supports efficient data handling and analysis. Most importantly, this approach lays the groundwork for downstream applications such as AI training and automated mix design optimization, paving the way for data-driven innovation in sustainable construction materials.

Keywords: Data management, Electronic lab notebook (ELN), Materials science, International collaboration, Machine-readable data

Sustainable Optimization Of Ultra-High-Performance Concrete Using Recycled Fines And Co_2 Mitigation: A Machine Learning And Swarm Intelligence Framework

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Abstract. The increasing environmental repercussions associated with cement-based construction materials, particularly ultra-high-performance concrete (UHPC), necessitate the adoption of innovative methodologies that enhance mechanical properties while mitigating carbon emissions. This investigation examines the ecological implications of UHPC and demonstrates how machine learning methodologies and advanced optimization techniques can enhance its mechanical properties while reducing carbon emissions by analyzing UHPC formulations incorporating recycled concrete powder (RCP). The Random Forest (RF) and Long Short-Term Memory (LSTM) models, augmented by Particle Swarm Optimization (PSO) and Chicken Swarm Optimization (CSO), were employed to forecast and optimize performance metrics. The dataset comprised 380 instances amalgamating real and AI-generated methodologies utilizing a Variational Autoencoder, encompassing the principal components of UHPC such as cement, fly ash, silica fume, and the water-to-binder ratio, with CO2 emissions serving as the dependent variable. Findings indicated that RF models, particularly RF-CSO and RF-PSO, attained high accuracy Root Mean Square Error (RMSE: 7.04), Mean Absolute Error (MAE: 4.16), whereas LSTM-PSO demonstrated superior performance in recognizing temporal patterns (RMSE: 46.22, MAE: 4.53), underscoring its capability to manage non-linear relationships. The standalone LSTM exhibited subpar performance, thereby accentuating the necessity for optimization. The optimized UHPC formulations realized a CO_2 reduction of up to 20.83%, congruent with the guidelines established by the Global Cement and Concrete Association (GCCA), thereby representing a significant advancement toward the development of low-carbon concrete solutions. The research accentuates the potential of machine learning and optimization techniques in facilitating sustainable, data-driven design of UHPC, with RF models requiring minimal hyperparameter calibration, while LSTM models necessitate more extensive refinement to ensure reliability and minimize errors.

Keywords: Ultra-high-performance concrete recycled concrete fine, CO_2 footprint, machine learning optimization, environmental sustainability, SDGs.

See full Paper in the Proceedings

FAIR Digital Objects for Structured Scientific Data: Concepts for Sustainable Registration, Discovery and Reuse

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Abstract. The increasing complexity and volume of simulation and experimental data in engineering and scientific domains demand robust strategies for data structuring, publication, and long-term accessibility. This contribution proposes a framework for encapsulating structured scientific data in FAIR (Findable, Accessible, Interoperable, Reusable) digital objects, registered in publicly accessible databases, and hosted in institutional or domain-specific repositories with persistent identifiers and long-term availability.

At the data level, the approach leverages JSON Schema to formally describe the structure of scientific data in a standardized, human-readable and machine-actionable format. Where applicable, these schemas can be extended to JSON-LD using domain ontologies, enabling semantic interoperability. At the metadata level, a knowledge graph is constructed using established standards such schema.org, enriched with schema-specific descriptors to support fine-grained discovery and filtering of data objects.

The paper discusses the conceptual and technical foundations of this approach and compares it to existing curated global databases, highlighting trade-offs in scalability, maintenance, and openness. Potential applications include the publication of data from round-robin tests, interlaboratory studies, and individual experiments, with the goal of fostering reproducibility, transparency, and community-driven validation.

By initiating a discussion on decentralized yet structured scientific data publication, this contribution aims to explore future pathways for sustainable data sharing and reuse in simulation and test-driven research.

Keywords: FAIR digital objects, data structures, database, knowledge graphs, ontologies.

See full paper in the proceedings.

Beyond ISO 5725-2: Robust Statistical Methods for Precision and Reproducibility in Materials Testing

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Abstract. Precision and reproducibility are critical for ensuring the reliability of measurement methods, especially in materials testing, where results influence design, safety, and compliance. Interlaboratory studies (round-robin tests) are a central tool in estimating these metrics. Traditionally, ISO 5725-2 has provided the statistical foundation for such analyses, relying on classical ANOVA-based methods and fixed rules for outlier detection. With advances in computational statistics, including robust statistical methods and mixed linear models, the ISO 5725-2:2019 update now explicitly permits modern alternatives. This contribution explores how robust linear mixed-models can enhance the analysis of precision and reproducibility data. The results demonstrate that robust methods provide greater stability against outliers and unbalanced designs, leading to more reliable estimates of variability components. The paper concludes with recommendations for practitioners and standards developers on adopting robust methodologies in precision studies.

Keywords: Performance-based testing, Measurement precision & reproducibility, Interlaboratory validation (ISO 5725), Robust mixed-effects models

See full paper in the proceedings.

A SEMANTIC WEB-BASED FRAMEWORK FOR DESIGN ASSISTANCE USING EUROCODES

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Abstract

Ontologies are formal, structured representations of domain knowledge that define concepts, properties, and relationships in a way that is both human- and machine-readable. Widely used in fields such as biomedical science, manufacturing, and geospatial data, ontologies support interoperability, reasoning, and knowledge reuse. However, their application in structural engineering, particularly in design, remains limited. This work addresses this gap by proposing a design-assisting framework based on Semantic Web technologies, using ontologies to model the core concepts and reasoning structures of the Eurocodes. The proposed framework provides an abstract semantic representation of Eurocode-based design logic and does not constitute a digital reproduction of the standards' textual content.

The framework models the Eurocodes' inherent modular organisation, making them well-suited for ontological encoding. Eurocodes are built on defined concepts and rules, which align naturally with ontology-based structures. A core ontology is developed to cover general structural concepts across material types and structural systems, compatible with widely accepted AEC ontologies. This central model is extended with material-specific modules (e.g., for concrete) and loading scenarios, following the structure of individual Eurocode parts. The use of Semantic Web technologies also supports multilingual vocabularies, enabling mapping between national Eurocode implementations and allowing for language-independent interpretation of design rules. The framework facilitates knowledge sharing and consistent interpretation of standards across different regions and platforms.

Currently, the framework supports simple structural verifications by enabling basic design checks, automating calculations, and validating input data and results. Looking forward, the structured knowledge encoded in the ontology offers a foundation for integrating data-driven methods, particularly through the use of neuro-symbolic AI. This could enable dynamic interaction with broader design repositories, enhancing the tool's ability to provide context-aware, intelligent design support. The approach promotes transparency, reusability, and consistency, and contributes to the development of next-generation digital engineering tools.

Keywords: Semantic Web, ontology, Eurocode, structural design, intelligent design tool.

Optimizing concrete mix design using a data-driven model

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Abstract. The production of cement accounts for approximately 7–8 % of global CO_2 emissions, making it one of the largest industrial contributors to the greenhouse effect. Despite its significant carbon footprint, concrete remains indispensable due to its durability, versatility, and availability. Reducing its environmental impact requires innovative formulations with lower clinker content and/or alternative raw materials. Such substitutions, however, often alter mechanical performance, durability, and workability, complicating optimization and increasing R&D costs. In this context, artificial intelligence (AI) and data-driven modeling offer powerful tools to accelerate formulation development. By analyzing large datasets of existing concrete recipes, it becomes possible to identify trends and build predictive models for low-impact mixes. In this study, a dataset of 11 430 mixes from 1 272 recipes was analyzed, including binder composition, water-to-cement ratio, aggregates, and admixtures as inputs, and compressive strength and workability as outputs. After data cleaning, normalization, and feature selection, the dataset was split 80:20 into training and test sets. The model, optimized via Bayesian hyperparameter optimization using Optuna, achieved an R^2 of 0.941 and MAE of 1.006 on the training data, and maintained good generalization (R^2 = 0.670, MAE = 3.375) on the test set, demonstrating the potential of AI to support sustainable concrete design.

Keywords: Low-carbon concrete; machine learning; data-driven modeling; concrete mix design; sustainability; compressive strength prediction

See full paper in the proceedings.



TIME-DEPENDENT BEHAVIOUR OF CAST AND PRINTED CONCRETE

Direct and indirect measurements of static yield stress of cement mortar for 3D concrete printing

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Abstract: This study investigates the time-dependent rheological behaviour of cement mortars formulated for 3D Concrete Printing (3DCP) with a focus on both direct and indirect methods for assessing static yield stress. Three experimental methods were used: two direct methods - (1) parallel plate rheometer and (2) shear vane rheometer - and one indirect method - (3) the mini slump test. Four mortar mixes with varying water-to-cement ratios were tested. The study analyses discrepancies among static yield stress values obtained from different methods and identifies the most suitable one for 3DCP applications.

A comparative analysis was carried out to relate the measured slump values with static yield stress, leading to the development of an empirical model. The model was validated through a series of 3D printing experiments. The results reveal an exponential correlation between slump and static yield stress, influenced significantly by the surface area-to-volume ratio (A/V) of test specimens. A generalised exponential expression is proposed to estimate static yield stress based on the measured slump and A/V ratio, which can be used to predict the maximum number of printable layers without plastic collapse. The empirical models have shown good agreement with experimental data, suggesting their practical utility in predicting printability based on time-dependent slump values.

Keywords: Static yield stress; 3D concrete printing (3DPC); Surface area-to-Volume (A/V); Mini slump; Printability.

See Full Paper in the proceedings

Time-Dependent Overhang Formation in 3D Concrete Printing: From Accelerator Baselines to Toolpath Strategies

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Abstract. Overhangs in 3D concrete printing (3DCP) are constrained by the time-dependent behaviour of fresh materials, where early-age stiffness and interlayer adhesion limit unsupported geometries. This study compares material- and toolpath-based strategies for medium-scale specimens (50 × 50 × 50 cm) with dome-like and funnel-like profiles that incorporate overhangs of up to 70°. Phase 1 established a baseline using planar slicing and accelerator dosages ranging from 0 to 10% bwoc, identifying 4% as the minimum viable content. Phase 2 applied this benchmark to four printing logics: planar slicing, adaptive layer height, adaptive filament width, and non-planar slicing. Buildability was assessed by maximum overhang, deformation, failure mode, and robustness. Results show accelerators improve support but plateau and reduce process reliability, while adaptive layer height and non-planar slicing achieved the highest overhangs (~70°). Findings highlight toolpath design as a more sustainable route than bulk admixture use, supporting hybrid, geometry-aware control strategies for 3DCP.

Keywords: 3D Concrete Printing (3DCP), Overhang formation, Toolpath strategies, Accelerator dosing, Geometric Freedom, Buildability

See Full Paper in the Proceedings

TEMPERATURE-DEPENDENT EARLY-AGE PROPERTIES OF 3D PRINTED CONCRETE

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Abstract

Reducing the uncertainty associated with discrepancies between laboratory characterization tests and the actual behavior of materials used in the 3D printing process remains a critical challenge. These variations often stem from systematic errors: despite using materials with the same mix design, test samples are not always sourced from the exact batch employed during additive manufacturing. Moreover, inconsistencies in equipment precision, specimen preparation, and curing conditions, often carried out in moulds, can significantly alter hydration kinetics. Environmental factors can further compound these effects, potentially compromising print quality or altering failure mechanisms, whether governed by elastic or plastic collapse. A central question thus emerges: can the uncertainty related to material variability, particularly deviations in rheological behaviour and structuration processes, be systematically quantified and minimised? This study proposes a novel methodology as a foundational step toward implementing a digital twin framework for 3D concrete printing (3DCP). The approach focuses on correlating the evolution of temperature (T) over time (t) with the rheological and early-age mechanical properties of fresh concrete. Temperature monitoring, performed via embedded sensors such as thermocouples and thermal cameras, is identified as a critical parameter due to its proven linkage with structuration and cement hydration. The methodology integrates real-time data acquisition with conventional tests, including uniaxial unconfined compression and direct shear tests, to track the evolution of material behaviour during the early stages of printing. By mapping temperature development to changes in material properties, the proposed framework aims to enhance process reliability and predictive capabilities, ultimately reducing variability between test outcomes and in situ performance. This work lays the groundwork for robust digital twin applications in 3DCP, enabling adaptive control strategies that respond to real-time material state variations.

Keywords: 3D Printing, Dormant Period, Temperature History, Early age properties, Structuration

MONITORING THERMAL PROPERTIES AND VOLUME CHANGES OF ALKALI-ACTIVATED MATERIALS BY USING ADVANCED EXPERIMENTAL TECHNIQUES

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Abstract

As autogenous and thermal strains are significantly high in alkali-activated pastes, it is necessary to investigate ways to reduce these. This research studies how the volume changes of pastes made from slag activated by alkalis can be mitigated by substituting part of the slag with limestone filler or metakaolin and how this impacts the early age behaviour of the material with a focus on the autogenous shrinkage and the thermal expansion coefficient by using a customized AutoShrink device developed at ULB for that purpose.

When slag is partially substituted by limestone filler at substitution rates of 15% and 30%, a maximal reduction in the compressive strength of 23% has been obtained. Isothermal calorimetry revealed that the limestone filler was not entirely inert and showed the effect of dilution which is linked to the increase in the solution-to-binder ratio when the substitution rate increases. The autogenous shrinkage magnitude decreased when substituting 15% of the slag while higher autogenous shrinkage magnitude was obtained when 30% was substituted. The coefficient of thermal expansion was slightly reduced and delayed when slag was substituted with limestone filler.

When slag is partially substituted by metakaolin, its effect on the autogenous shrinkage and the coefficient of thermal expansion were found to depend on both the type and concentration of the alkaline activator. The swelling was increased at 10% substitution followed by constant shrinkage in case of NaOH-activation. Shrinkage was mitigated with Na_2SiO_3 activation. Higher substitutions with 8 M NaOH resulted in a significant increase in the shrinkage rate and thermal expansion coefficient (CTE). A 10% substitution delayed the CTE increase but resulted in higher later-age values (dilution effect). The 20% substitution led to a similar final CTE value at 300 h, while 30% substitution resulted in a decrease in CTE after the initial increase.

Keywords: blast-furnace slag; limestone filler; coefficient of thermal expansion; autogenous strain; metakaolin, alkali-activated.

Characterizing the Early-Age Viscoelastic Behavior of 3D Printable Concrete Using Stress Relaxation Tests

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Abstract. The viscoelastic behavior of early-age cementitious materials is particularly significant in applications such as 3D concrete printing, where time-dependent deformation can affect performance parameters such as shape retention. In this study, stress relaxation tests were carried out on fresh 3D-printable concrete mixtures. Two types of mixtures were examined: a control mixture prepared with Portland cement, and another incorporating a limestone–calcined clay addition. An amplitude sweep was first performed to identify the linear viscoelastic region (LVER), and a strain level corresponding to 40% of the LVER limit was selected to ensure linear viscoelastic response. Relaxation tests were conducted on samples with different ages—1, 10, 20, and 30 minutes after mixing—by applying a constant shear strain and recording stress decay over 100 seconds. The results revealed a substantial stress relaxation capacity, with more than 40% of the initial stress dissipating within 100 seconds. The LC2 mix exhibited higher stiffness development and a slower stress relaxation rate compared with the control, indicating a more elastic-dominated response at early ages. The relaxation modulus, calculated by normalizing stress over time with the applied strain, showed good agreement with the generalized Maxwell viscoelastic model having two relaxation times. These insights enhance the understanding of early-age viscoelasticity and offer valuable input for modelling buildability and evaluating time-dependent stresses arising from plastic shrinkage and thermal effects during early-ages in 3D-printed concrete.

Keywords: 3D-printable concrete, Viscoelasticity, Generalized Maxwell model, Supplementary cementitious materials.

See full paper in the proceedings.

Short-term Creep Response and Anisotropic Strength of 3D Printed Concrete in Compression

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Abstract. 3D concrete printing is increasingly being adopted in construction, yet limited knowledge exists on the creep behaviour of printed elements, particularly in the hardened state. This study presents an investigation into the short-term creep behaviour of 3D printed concrete (3DPC) under compressive stress. Printed samples reinforced with micro-synthetic polypropylene fibers were compared with conventionally cast samples of the same mix. A sustained load of 35% of the ultimate compressive strength was applied for 30 days to evaluate time-dependent deformation. The microstructural evolution of cast and printed samples was investigated using X-ray computed tomography, with particular focus on porosity and CT imaging to examine its influence on mechanical properties. Experimental results highlight pronounced anisotropy in the mechanical response of printed samples, with cylindrical samples reaching 75% and 76% of the compressive strength of cubic counterparts for cast and printed samples, respectively. Cast samples generally outperformed printed ones, while higher creep strains were recorded in printed samples, attributed to increased porosity and interlayer voids. These findings emphasize the need to account for creep in the hardened state when designing with 3DPC.

Keywords: 3D printed concrete, Polypropylene fibers, Compressive stress, Anisotropic strength, Creep strains, Microstructure.

See full paper in the proceedings.

COMPARISON OF CREEP AND SHRINKAGE MODELS IN THE CONTEXT OF CONCRETE EXPOSED TO ELEVATED TEMPERATURES

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Abstract

Concrete is a key material in nuclear infrastructure, particularly in high-level radioactive waste disposal systems and reactor containment buildings, where it must withstand elevated temperatures and fluctuating humidity. As part of an initiative to characterize candidate materials for deep geological disposal tunnel lining design, recently, an extensive experimental dataset has become available for a high strength concrete exposed to a temperature range of 20-85°C and varying relative humidity. The laboratory programme has yielded results based on isothermal and semi-adiabatic calorimetry, thermogravimetric analysis, pore structure characterization, mass loss, permeability, mechanical properties, as well as basic and drying shrinkage and creep tests. This extensive dataset enables the validation of a standard continuum-based thermo-hydro-chemical-mechanical (THCM) model developed as a tool to estimate long term stability of different designs of tunnel linings. In particular, this study focuses on simulating experimental results concerning creep and shrinkage at different temperatures. For instance, the results show that at 85°C, both basic and drying creep in concrete increase significantly after 200 days, with drying creep showing a greater relative increase. These increases, while substantial, are lower than those re-ported in other studies, suggesting that curing duration and mix design influence the phenomenon magnitude. The Pickett effect, representing additional deformation under drying conditions, is influenced by both temperature and curing age. It intensifies at elevated temperatures but diminishes as the curing age increases. In the past, there have been a number of creep and shrinkage models proposed by the scientific community. While the authors primary aim to demonstrate the capability of the reformulated microprestress theory (MPS), given the recent advances with the extended microprestress theory (XMPS), the second goal is to demonstrate the performance of the latter. The THCM model with MPS and XMPS is implemented in COMSOL software with the available in built COMSOL modules and external subroutine.

Keywords: This list is requested for the abstract submission. Please limit the list to a maximum of 6 items.

Software for Mechanical Characterization and Design of Textile-Reinforced Concrete in Flexure

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Abstract. Reliable design of textile-reinforced concrete (TRC) structures depends on accurate characterization of the material's behavior. The performance of TRC is governed primarily by its tensile response. A flexural test can serve as an effective alternative to direct tension testing. This work presents a closed-form analytical moment-curvature model for TRC that enables both forward and inverse analysis. Using this approach, tensile stress-strain curves are back-calculated from flexural test data. A MATLAB-based, graphical user interface (GUI) software was developed to assist researchers in extracting the tensile model of TRC materials and performing forward simulations for design and analysis. The model allows the extraction of tension and compression stress-strain responses, force carried by each component as a function of the changing neutral axis, and the evolution of stress and strain distribution with increasing deflection. The extracted constitutive model can further be applied to assess long-term and time-dependent effects such as fatigue, creep, shrinkage, and prestressing, and to perform limit state analysis of beams and columns. The tool has been validated against experimental results from multiple TRC systems. Designs based on back-calculated material properties are also compared with the performance of structural beams, demonstrating the model's scalability and design applications.

Keywords: Back-calculation, Inverse-Analysis, Tension Model, TRC, GUI, Software

See full paper in the proceedings.

ASSESSMENT OF THE APPLICABILITY OF CONVENTIONAL SHRINKAGE PREDICTION MODELS TO LIMESTONE CALCINED CLAY CONCRETE

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Abstract

An accurate prediction of the time-dependent strains of hardened concrete is essential for ensuring long-term durability and structural performance. Existing models for predicting the shrinkage, such as ACI 209R, Bažant B4, *fib* MC 2020, and GL2000, were primarily developed for conventional Portland cement (PC) concrete. However, the majority of modern concrete used in infrastructure construction today contains supplementary cementitious materials (SCMs). As such, the accuracy of existing shrinkage prediction models for concrete incorporating SCMs remains to be verified experimentally. This investigation attempts to assess the applicability of these prediction models to sustainable limestone calcined clay (LC^3) concrete.

Shrinkage measurements were collected from unrestrained OPC and LC^3 concrete prisms (75 × 75 × 200 mm in size) under controlled environmental conditions (RH = 65 ± 5 %, T = 21 ± 3 °C). Up to 90 days, the ACI 209R model achieved the best predictions; the prediction errors were +23.4 % and -5.06 % for the reference OPC concrete and LC^3 concrete, respectively. Between ~91–300 days, the *fib* MC 2020 model was the most accurate; +6.2 % and +1.1 % for the OPC concrete and LC^3 concrete, respectively, although the r^2 value was low for the LC^3 concrete (r^2 = 0.65) compared to OPC concrete (r^2 = 0.94), due to the inaccuracies observed up to 90 days. From 301 to 520 days, the most accurate models for predicting the shrinkage of the OPC concrete were the ACI 209R and *fib* MC 2020 models, however, it was the Bažant B4 and GL2000 models which provided the best predictions for the LC^3 concrete. These findings suggest that shrinkage models calibrated for PC-based concretes with typical compositions are not directly applicable to the LC^3 concrete. For improved shrinkage predictions of LC^3 concrete, more refined models including calibration factors have been proposed.

Keywords: Sustainable concrete, LC^3 concrete, shrinkage, concrete shrinkage modelling

Using superabsorbent polymers for curing of expansive concrete

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Abstract. Expansive concrete is used for chemical prestressing. Its essential ingredient is expansive calcium sulfoaluminate (CSA) cement. Based on previous research, expansive concrete must be cured underwater for a minimum of three to four weeks to ensure full expansion. It is evident that such a long period is not practical for the construction industry. Therefore, this paper investigates internal curing with superabsorbent polymers (SAP) as an alternative approach. The first step was to determine the absorption rate and potential long-term storage capacity of SAP by the "tea-bag method" using specifically extracted CSA pore solution as the absorption medium. Based on these findings, the SAP and the predetermined amount of curing water were added "on top" of an established expansive concrete mixture. In this parameter study, different amounts of SAP and water additions were tested. After demolding the specimens, curing was continued in standard laboratory climate, and expansion was measured on selected days over a 21-day period. Finally, flexural and compressive strengths were determined. Results illustrate that the SAP can, indeed, sustain the expansion process. However, the achieved expansion was less than that of the SAP-free reference cured underwater. Besides, a decrease in strength was observed with increasing SAP dosages and internal curing water, which is in line with trends of ordinary concrete. However, curing under ambient air conditions instead of underwater with a still acceptable degree of expansion may prospectively be beneficial for practical applications from procedural, labor, and cost perspectives.

Keywords: Expansive Concrete, Chemical Prestressing, Calcium Sulfoaluminate, Superabsorbent Polymers, Curing Methods.

See Full Paper in the Proceedings.