2nd INTERNATIONAL CONFERENCE ON

INNOVATION IN LOW-CARBON CEMENT & CONCRETE TECHNOLOGY

LONDON 8 - 10 JULY 2024

BOOK OF ABSTRACTS

Editors: Yun Bai, Yanfei Yue, Raman Mangabhai, Jun Ren, Shi Shi

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Book of Abstracts of the 2nd International Conference on Innovation in Low-Carbon Cement & Concrete Technology

Held at

University College London, Gower Street, London
8 - 10 July 2024

Edited by

Yun Bai
Yanfei Yue
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PREFACE

This is a much overdue conference which is eventually taking place on 8-10th July 2024 in London. As most of you may have already known, followed by the success of the First International Conference on Innovation in Low-Carbon Cement and Concrete Technology (ILCCC2019) organised by the Advanced and Innovative Materials (AIM) Group at University College London on 24-26th June 2019 in London, the second ILCCC was originally scheduled for July 2022 in London again. However, the date of the second ILCCC has been postponed several times due to Covid-19 pandemic. We are very pleased to see that, even after suffering so many uncertainties, ILCCC has still been strongly supported by our cement and concrete community as evidenced by the 159 papers received from more than 20 countries. The conference is again organised into four plenary sessions but with more parallel sessions compared to the first conference (now 18 sessions), including 10 keynote presentations and 89 oral presentations, together with 15 posters on various topics related to low-carbon cement and concrete technology. In particular, we are delighted to see that there are 45 students entering the student competition to compete for 10 different prizes in various categories. This is very exciting because these students are the future of low-carbon cement and concrete. It is, indeed, our great pleasure to be able to provide such a platform for them to develop their future career in field of low-carbon cement and concrete.

Moreover, ILCCC2024 is deemed to be unique in the history of cement and concrete conference as it also celebrates the bicentenary of Joseph Aspdin's patent for Portland cement by dedicating the first two plenary sessions to this special celebration. In particular, the talk given by Professor Ian Richardson on 'The invention and nature of Joseph Aspdin's patent Portland cement' as well as the one by Professor Karen Scrivener on 'History of hydration, from Le Chatelier to low carbon' will not only give us some historic and technical aspects about Portland cement, but will also highlight the importance to achieve low-carbon for this very important material which has transformed human civilization in the past. This, together with the roadmaps published recently in several countries, including the 'UK Concrete and Cement Industry Roadmap to Beyond Net Zero', will, no doubt, guide the future direction of low-carbon cement and concrete.

It would have not been possible to run a conference like this without the support from different parties. The editors would like to thank all sponsors, exhibitors and advertisers for their support. We also wish to thank the members of the international scientific committee and the Institute of Concrete Technology (ICT), the Institute of Materials, Minerals and Mining (IOM3), the Mineral Product Association (MPA), Réunion Internationale des Laboratoires et Experts des Matériaux (RILEM) for supporting this event. The editors would also like to thank the tremendous support received from the members of the organising committee. The thanks, in particular, go to Yuqi Shen, Leqing Lin, Jingbo Wang, Wen Sun, Birunxuan Liu, Yunhong Cai and Judith Zhou for their hard work and support in the past more than one year for organising and preparing this conference.

Followed by the success of the two ILCCCs, it is our intention to run this conference every three years from now onwards. This will allow us to report regularly the latest global scientific and technical achievements in low-carbon cement and concrete technology in order for the cement and concrete community to make our own contribution to save this planet.

Yun Bai
Yanfei Yue
Raman Mangabhai
Jun Ren
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www.iom3.org

rilem

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www.rilem.net

mpa

The Mineral Products Association (MPA) is the UK's trade association for the aggregates, asphalt, cement, concrete, dimension stone, lime, mortar and silica sand industries. It has a growing membership of 480 companies and is the sectoral voice for mineral products. MPA represents its members' interests on policy, planning and technical matters with government departments, local authorities, professional trade bodies and other key audiences at European, national and local levels.
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Southeast University (Southeast University for short), located in Nanjing, is a comprehensive, research-oriented university with engineering as its main feature. It is a national key university directly under the Ministry of Education and jointly built with Jiangsu Province. It is also a key university under the national "Double first-class", "Project 985" and "Project 211" construction, and one of the first batch of pilot universities under the Ministry of Education's "Three comprehensive education" comprehensive reform.
www.seu.edu.cn

Xi 'an University of Architecture and Technology, referred to as "Xi 'an Jiandu" or "Xi 'an Jiandu" (XAUAT), located in Shaanxi Province, is a full-time general undergraduate college under the supervision of Shaanxi Province. It is a university jointly built by the Ministry of Housing and Urban-Rural Development of the People's Republic of China, the Ministry of Education and the Shaanxi Provincial People's Government. It is one of the "Eight old architecture universities" and a university with "characteristic key discipline Project". Shaanxi Province is a high-level university; Selected 111 project and other projects. The school is characterized by civil architecture, environmental municipal affairs, materials metallurgy and related disciplines, with engineering and technology as the main discipline, and the coordinated development of multiple disciplines.
cn.xauat.edu.cn

Qingdao University of Technology, referred to as Qingdao University of Technology, is located in Qingdao City, Shandong Province, is a full-time general higher education institution under the administration of Shandong Provincial Department of Education. It is a multidisciplinary university focusing on engineering, with distinct characteristics of civil architecture, machinery manufacturing, environment and energy disciplines, and coordinated development of disciplines such as science and technology, economics, management, grammar and arts. It is one of the first national "111 Plan" construction units of local universities, one of the first national demonstration universities to deepen innovation and entrepreneurship education reform, and one of the first high-level universities in Shandong Province to build "strong characteristics" universities.
www.qut.edu.cn

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Jaystart Education has established partnerships with universities in major study destinations such as the UK, the USA, Australia, Canada, and New Zealand. The company's goal is to help every student gain admission to their ideal university, receive a diverse international education, and ultimately embark on a broader and higher professional career path.

KEYNOTE SPEAKERS

Ian Richardson

University of Leeds
United Kingdom

Ian Richardson is Professor of Civil Engineering Materials at the University of Leeds, UK. He received a D.Phil. from the University of Oxford in 1991 and has been at Leeds since 1995. He is a materials scientist whose main research interests concern advancing understanding of the microstructure, chemistry and properties of cementitious materials and related phases. He is perhaps best known for his work on the composition, morphology, and structure of the main binding phase in concrete. He has given numerous invited contributions at conferences or congresses. He is the Chairman of the Cementitious Materials Subgroup of the UK's Institute of Materials, Minerals & Mining, and he is currently revising Taylor's classic book Cement Chemistry.

Karen Scrivener

EPFL
Switzerland

Karen Scrivener has been Professor and Director of the Laboratory of Construction Materials in the Department of Materials of EPFL (Ecole Polytechnique Federale de Lausanne) for the last 20 years. She is a Fellow of the UK Royal Academy of Engineering and author of over 200 journal papers.

Her research focusses on the understanding the chemistry and microstructure of cement based materials and improving their sustainability. In 2008, she came up with the idea for LC^3 cement, this material has the potential to cut CO_2 emissions related to cement by more than 400 million tonnes a year.

Edwin Trout

The Concrete Society
United Kingdom

Edwin has worked in cement and concrete since 1995, when he joined the British Cement Association. His role transferred to The Concrete Society in 2006, and since 2011 has also acted part time as Executive Officer for the Institute of Concrete Technology. (He was elected an Honorary Fellow at the Institute's 50th Convention in 2022.)

With responsibility for the Concrete Society's library – established by the C&CA in 1937 – Edwin developed an interest in early concrete construction and the history of the cement and concrete industries, on which he has given talks and written articles for concrete sector periodicals, including the more specialised Construction History Journal and The Construction Historian. He writes a regular column in Concrete magazine and an ongoing series on Pioneers of Concrete Technology in the ICT Yearbook. He has contributed chapters to several collaborative books, including Lea's Chemistry of Cement and Concrete (Butterworth-Heinemann, 2019), Physical Models (Ernst & Sohn, 2020) and An Introduction to the History of Concrete Structures (fib, 2023). His own book, Some Writers on Concrete, was published in 2013, and another on nineteenth century cement mills in 2015.

Tongbo Sui

Sinoma
China

Dr. Tongbo SUI is currently vice president of Sinoma Int'l, CNBM. He has been intensively engaged for over 20 years in R&D of belite-based low energy & low CO2 clinker cements and led to the successful application of reactive belite-rich Portland cement in many hydropower projects of China. His recent research on calcined clay resulted in the development of energy efficient suspension calcining technology for thermal activation of clay.

He is now also visiting professor at University College London of UK and senior advisor of China Cement Association. He is also co-chair of WKG5 for Cement Innovation under GCCA and Fellow of ICT, UK.

Before joining Sinoma, he worked at China Building Materials Academy (CBMA) since 1991 and as vice president of CBMA during 2006-2010.

Changwen Miao
Southeast University
China

Miao Changwen, academician of Chinese Academy of Engineering (CAE), building materials expert, professor and doctoral supervisor of Southeast University, director of the Academic Committee of Southeast University, Chairman of the International Joint Laboratory for Advanced Civil Engineering Materials, Chairman of International Green Building Alliance.

Miao Changwen is mainly involved in theoretical and technical research on civil engineering materials and has made great contribution in the research areas of key technology of crack resistance of concrete, service life extension and durability improvement of infrastructure, and multifunctional materials for civil engineering. He has been awarded Second Class of National Technological Invention Award, Second Class of National Technological Advancement Award (three times), First Class of Provincial and Ministerial Scientific and Technological Progress Award (seven times). In addition, Miao Changwen was authorized 82 national invention patents, published 4 monographs, and published more than 200 papers, including more than 150 papers indexed by SCI, EI or ISTP.

Angel Palomo
Eduardo Torroja Institute for Construction Science
Spain

Professor at the "Eduardo Torroja" Institute for Construction Science in Madrid, Spain, holds a PhD in Chemistry and boasts a research career spanning over 40 years since 1982. His primary research focuses on the chemistry of Portland cement and the development of new sustainable cementitious materials, particularly alkaline cements. With a prolific record, he has authored over 200 papers in scientific journals, delivered keynote lectures at more than 100 international events, and served as the General Secretariat for Alkali Activated Materials Group at RILEM. Professor Palomo has played key roles in organizing major conferences and actively contributes to the Steering Committee of the International Congress on the Chemistry of Cement (ICCC) at global venues. Additionally, he serves as a collaborator and advisor to the international industry on sustainable cement and concrete practices.

Johann Plank
Technische Universität München
Germany

Prof. Plank holds a Ph.D. in chemistry. From 1980 – 2000 he held positions as Research Group Leader, Director of Research “Construction and Oilfield Chemicals” and finally General Manager of SKW Polymers GmbH, Trostberg where he invented numerous concrete & mortar additives and oilfield chemicals. Since 2001 he is Full Professor of Construction Chemistry at Technische Universität München, Department of Chemistry. His current research is focused on novel low carbon “green” binders, polymeric admixtures (esp. polycarboxylate superplasticizers) for concrete and mortar, CO2 footprint of concrete admixtures, nanoparticles, organic-inorganic hybrid materials, 3D printing and energy harvesting floors. Prof. Plank has published over 500 scientific papers, holds 40 patents, has guest professorships in Singapore, Tokyo, Shanghai, Beijing and Iraq, is member of numerous professional organizations including GDCh, RILEM, SPE, API, recipient of the A. Aignesberger Award from CANMET/ACI and a “1000 foreign expert” in China. Since 2021 he is TUM Professor of Excellence, a member of TUM´s Senior Excellence Faculty and in 2023 was elected into the German Academy of Sciences.

Chi Sun Poon
PolyU
HK, China

Ir Prof. Chi Sun POON obtained his PhD from Imperial College London. He joined The Hong Kong Polytechnic University (PolyU) as a lecturer in 1992. Currently, he is the Michael Anson Professor in Civil Engineering, Chair Professor of Sustainable Construction Materials, Head of the Department of Civil and Environmental Engineering (CEE), and Director of the Research Centre for Resources Engineering towards Carbon Neutrality (RCRE) at PolyU. He is also one of the Directors of the PolyU-NAMI 3D Concrete Robotic Printing Research Centre (RCC3D). He was awarded the title of Changjiang Chair Professor by the Ministry of Education in 2017. Ir Prof. Poon specializes in the research and development of environmentally friendly construction materials, waste management, waste recycling technologies, concrete technologies, and sustainable construction. He has been an Editor of Construction and Building Materials since 2014 and an Editorial Board Member of Cement and Concrete Composites since 2017. Ir Prof. Poon has published over 700 papers in international journals and conferences, including 580 international journal papers, 160 refereed conference papers, and 6 book chapters. His current h-index is 108, with a total of over 42,000 citations in Scopus. He holds more than 10 patents related to concrete and waste recycling technologies. He has been listed among the World's Top 2% Scientists by Stanford University. He received the State Technological Innovation Award 2017 (2nd Class). Ir Prof. Poon is a Fellow of the Hong Kong Institution of Engineers (HKIE), a past Chairman of the HKIE Environmental Division, and a past Panel Chair and Representative of the HKIE Environmental Discipline. He is currently a Professional Assessor of the HKIE Environmental Discipline. He is a Fellow of the Hong Kong Concrete Institute (HKCI) and a past President of the HKCI. Additionally, he is a past President of the American Concrete Institute (China) Chapter. He has served on the Advisory Council on the Environment (ACE) and the Council for Sustainable Development and is currently a member of the Advisory Committee for the Green Tech Fund.

Richard Ball
University of Bath
United Kingdom

Dr Richard Ball is a Reader in the Department of Architecture and Civil Engineering at the University of Bath. He graduated from the University of Bath with a BEng in Materials Science and Engineering and a PhD in Materials Science. He has published over 110 papers in refereed international journals covering ceramics, composites, nanomaterials, air quality, heritage materials, and 3D printing. His recent research has focused on materials for additive manufacturing using autonomous aerial robots. He is a chartered engineer, chartered scientist and a fellow of the Institute of Materials, Minerals and Mining.

Colum McCague
MPA
United Kingdom

Colum boasts a wealth of experience in overseeing major research and development (R&D) initiatives for the UK cement industry. Notably his leadership on a project led to a significant revision of the UK concrete standard in 2023 which now provides guidance on multi-component cements containing as low as 35% clinker. Before joining the MPA in 2015, Colum worked at the Research Centre for Photonics and Instrumentation at City, University of London, where he successfully developed optical fibre sensing solutions for industry-driven R&D projects. Colum earned his MEng degree in structural engineering and later obtained a Ph.D. in civil engineering from Queen's University Belfast in 2009 and 2015, respectively. He is an Honorary Lecturer at University College London and a member of both the Institute of Concrete Technology and the Institute of Materials, Minerals, and Mining.

KEYNOTE LECTURE

The invention and nature of Joseph Aspdin's patent Portland cement

Ian G. Richardson[1], Xiaohong Zhu[1], Paul L. Dawson[2], Phil Judkins[2], Mark J. Richardson[3]

[1] School of Civil Engineering, University of Leeds, Leeds LS2 9JT, West Yorkshire, UK
[2] Wakefield Historical Society, Wakefield, West Yorkshire, UK
[3] Independent Researcher, Scunthorpe, North Lincolnshire, UK
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ABSTRACT

Portland cement has been central to the development of the modern world, with billions of tonnes now used annually. It is perhaps surprising therefore that its early history is shrouded in mystery, and that there is no consensus about the identity of the inventor. Whilst Joseph Aspdin, a bricklayer from Hunslet, Leeds, was granted a British patent in 1824 for a material that he called Portland cement, conclusions differ considerably on how similar Joseph's material would have been to the Portland cement that is in use today. For example, Blezard (1998) believed that Joseph had produced "Nothing more than a hydraulic lime", whereas Skempton (1962) stated that "The truth would seem to be that the 'break-through' [of clinkering] had been made by 1843 at the latest, and more probably a good deal earlier by the elder Aspdin [i.e. by Joseph rather than his son William]." We recently acquired a sample of render from a former public house that is widely considered to be "...the only surviving example of a building covered with Joseph Aspdin's patent Portland cement" (Historic England List Entry 1245773). In this lecture, I shall present results from our microstructural characterization of that sample combined with historical research, and – in this bicentenary year of his patent – demonstrate that Joseph most likely did invent Portland cement the material as well as the name. The evidence includes contemporary images that indicate that the second of his kilns in Wakefield would have been able to reach the high temperatures that are necessary to produce Portland cement.

History of Hydration, from Le Chatelier to Low Carbon

Karen Scrivener

EPFL, Switzerland

ABSTRACT

The hydration of cement if the key process which governs the almost magical transformation of concrete from a fluid, placeable material to a strong durable solid. Despite this importance there are still many unknowns about this process. This year we are celebrating 200 years since the patent of Joseph Aspdin which christened "Portland" cement. However, in this presentation I would like to look at the somewhat shorter history of understanding the hydration mechanism. In 1887 the PhD thesis of Le Chatelier was probably the first significant work to tackle this subject. By 1918, at what is usually regarded at the First ICCC there was a heated debate between Le Chatelier and Desch between (what we now call) the "through solution theory" and the "colloidal" hardening theory. In this presentation I will summarize some of the aspects of the main research on hydration in the nearly 140 years since the work of Le Chatelier: Theories of the induction period; why the reaction slows down after less than a day; the structure of C-S-H and how supplementary cementitious materials react. Understanding hydration is still central today to understanding how we can reduce to a minimum the environmental impact of cement based materials – here I will identify areas where I think future research is important.

A history of calcareous cements: Precursors to Portland cement, 1756-1824

Edwin A.R. Trout

The Institute of Concrete Technology
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ABSTRACT

Joseph Aspdin's invention of Portland cement in 1824, whose bicentenary we celebrate this year, did not emerge from a vacuum. The search for a hydraulic binder suitable for the constructional needs of the age – applicable to civil engineering, widely available and economically priced – had been pursued in both theory and practice for several decades beforehand and an understanding of the requisite geology and chemistry gradually accumulated. Knowledge of progress was transmitted through personal contact and increasingly through specialist publications.

Keywords: History; hydraulic lime; natural cement; Portland cement

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Centurial evolution of Chinese cement industry

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ABSTRACT

Portland cement (PC) has played very important role in contributing to the civilization and social progress of human beings during the last 2 centuries since its invention symbolized in 1824 in UK. Now the resultant PC concrete has become the 2nd largest commodities after water. This is of great significance for China which at present produces and consumes about 50% of world cement. A review of the progress of China cement industry since it was introduced into China in the late 19th century is made in one hand to demonstrate the persistent effort and pathways of the industry, and to dedicate to the 200 years anniversary of Portland cement as well. Three phases of the development of China cement industry are introduced briefly with the characteristic events happened in each phase, i.e., the 1st phase 1886-1949, the starting of the industry in a turbulent age, the 2nd phase 1949-1978, the industry reviving with the new China, and the 3rd phase 1978-now, the strong growth period with economy booming. As analyzed, the main progress takes place after 1949, particularly in the past 20 years showcased by a fundamental overall restructuring of the industry in terms of products quality and new binders development, process technology and equipment, energy efficiency, pollution control, emission mitigation, and wastes co-processing, etc. Future perspectives of China cement industry are also discussed towards the common goal of carbon neutrality and sustainability of the global cement sector.

Green and low-carbon construction materials

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ABSTRACT

Civil engineering materials constitute the foundational basis for significant national infrastructure projects in sectors including transportation, construction, water resources, energy, and defense. The advancement of the "dual carbon" strategy and the emergence of new engineering structure construction have put forward higher requirements for civil engineering materials. This report will introduce the low carbon cementitious materials, the low carbon concrete products and the high performance concrete. Aligned with the national dual-carbon strategy and the exceptional demands of future major engineering projects on the performance of civil engineering materials, we proposed a new paradigm based on deconstruction, reconstruction, and upgrade-construction research approaches. This paradigm introduces the innovative concept of creating cement-based biomimetic metamaterials (CBMs) through biomimetic sequential fabrication, anchored in the cementitious gene (C-S-H). It advocates cross-scale architectural techniques and significant performance leap methodologies for the biomimetic microstructure of CBMs. Incorporating data-driven and high-throughput screening methodologies for intelligent design, this approach aims to surmount the scientific and technological bottlenecks associated with integrating multiple materials, multi-scale sequential architectures, multi-functionality, and multi-scenario applications in CBMs. The development of this new class of biomimetic CBMs, exemplified by biomimetic superhydrophobic concrete, biomimetic high-strength and toughness concrete, cement-based biomimetic aerogels/hydrogels, cement-based biomimetic photothermal metamaterials, promises to revolutionize the mechanical and functional capabilities of civil engineering materials. The report provides reference for meeting new demands of the construction industry and coping with the challenges of carbon neutrality.

Sustainable cements: an urgent need

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ABSTRACT

Nowadays cement factories are producing more than ever before. Between 2010 and 2018, emissions from the cement industry increased by approximately 6.6% despite the 2015 Paris Agreement to reduce GHG emissions. The roadmaps of most of huge European, American and Asian cement/concrete producers point to very significant use of CCUS (40%-65%) to meet the 2050 decarbonization ambitions; but this roadmap will have an extremely limited impact prior to 2030. Moreover, the very expensive and not still clear transition from the current situation to the implementation of CCUS makes many institutions to hesitate about the feasibility of this plan. Let's remember that CEMBUREAU is still claiming to the European Governments for the fast construction of a European transnational infrastructure through which the transportation of CO2, from about 200 factories to one or several geological sinks, should take place.

There is no Plan B for this Roadmap even if today: i) Arising one CCUS unit may cost about 1000 million €; ii) 75% of CCUS projects in the world have failed; and iii) The needed infrastructure for transportation of CO2 has a cost of 15.000 million euro only in a territory of the size of Germany.

This work is a vindication of a *cheap* and rational alternative to achieve the objective of a cement industrial sector having zero emissions much earlier than that proposed by CEMBUREAU. It means, not considering **clinker** like an unavoidable component of cements.

Summarizing, this work is proposing the almost total replacement of clinker in cements by a very reactive synthetic **low carbon material** having a chemical composition similar to the one of a mixture of a *fly ash and a blast furnace slag*, and a mineral nature almost 100% amorphous.

New admixtures for low-carbon "Green" binders

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ABSTRACT

Concrete is the most commonly used man-made material globally. Regretably, cement – its major ingredient – exhibits an extremely high CO_2 footprint. Substituting cement clinker with supplementary cementitious materials (SCMs) of low carbon footprint can substantially decrease CO_2 emission. The two main alternatives to clinker include calcined clay and slag (GGBS). A prominent example of a low carbon binder based on thermally activated (calcined) clay is LC3 which contains 50% clinker, 30% calcined clay, 15% limestone and 5% gypsum. Its CO_2 footprint is 550 – 600 kg CO_2/ton. Novel tailored chemical admixtures present the key to achieve sufficient workability (especially slump retention) of such calcined clay blended cements because of their higher water demand as compared to OPC. Furthermore, depending on the individual composition of the raw clay, also admixtures to boost early (1 day) strength are required. Another concept for clinker substitution involves slag (GGBS) from the iron industry and – at high clinker replacement rates – an alkali activator. An extreme example of such AAS binders is comprised of 15% clinker, 82% slag and 3% alkali activator. This binder allows to reduce CO_2 emission from ~ 825 kg CO_2/ton for OPC to ~ 220 kg CO_2/ton and hence is climate neutral. Unfortunately, conventional PCE superplasticizers are insoluble in theses activator solutions based on NaOH, Na_2SiO_3 or Na_2CO_3, and hence ineffective. The paper presents approaches to implement a novel design for PCE superplasticizers providing exceptional dispersing efficiency in these binders. Finally, the decisive role of chemical admixtures in the transition to "green" binders is highlighted.

Keywords: CO_2 Emission; Calcined Clay; Admixtures; PCE Superplasticizer; Accelerator

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Development of low carbon construction materials through innovative recycling of waste materials

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ABSTRACT

The cement and concrete industry is a major solid waste producer and CO_2 emission contributor, posing considerable challenges in achieving a circular economy and carbon neutrality. To address the challenges, we developed different active carbonation technologies and strategies for the total recycling of waste concrete and the production of low-carbon construction products, including low-carbon and value-added materials, low-carbon blocks, functional carbonation coating, CO_2-activated concrete production etc., that innovatively circulate greenhouse gas and solid wastes from the construction industry as well as endorse high added value. This approach envisions that materials used in one building can be reclaimed and repurposed in new construction products while sequestrating CO_2 and reducing carbon emissions.

To enhance the utilization of solid wastes in the construction sector, a high-performance, low-carbon eco-cement with outstanding CO_2 sequestration capabilities was developed using incinerated sewage sludge ash (ISSA) and recycled concrete fines (RCF). The findings revealed that the eco-clinkers synthesized achieved a utilization rate of 95% (comprising 20% ISSA and 75% RCF), thereby maximizing solid waste recycling. These eco-clinkers exhibited high belite content, and the carbonated eco-cement pastes demonstrated superior compressive strength compared to OPC. Owing to the high CO_2 reactivity of the C_2S component, the low-carbon eco-cement pastes exhibited remarkable CO_2 sequestration capacity, achieving a high degree of carbonation after just one day of carbonation curing.

Keywords: Solid wastes; Recycled Concrete, Low-carbon construction materials, Eco-cement; Carbonation;

Materials for aerial additive manufacturing

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ABSTRACT

Additive manufacturing, better known as '3D printing' is being increasingly investigated as a method of constructing buildings. Typically, deposition platforms involve large ground-based gantries or robotic arms. Aerial Additive manufacturing is the world's first project to demonstrate the feasibility of multiple self-powered untethered drones extruding material in flight to construct multiple layers. Use of drones requires the miniaturisation of the additive manufacturing deposition process and the use of lightweight cementitious material. Material in the fresh state needs to exhibit pseudoplastic (shear thinning) behaviour. This involves the material possessing a reduced viscosity while under stress in the deposition system, which then increases by orders of magnitude once deposited thereby minimising deformation due to self-weight and the weight of subsequently deposited layers. Cellulose and xanthan gum were used as rheology modifying admixtures to promote pseudoplastic behaviour, with fly ash and smooth-particle sand used to aid workability. The addition of fibres can improve the flexural and compressive strengths and improve buildability but may decrease the workability of the mix. The addition of tungsten disulphide inorganic fullerene nanoparticles was demonstrated to improve mechanical properties and the impact resistance of 3D printed material. Aerial additive manufacturing could enable work in elevated or challenging site conditions and promote architectural freedom in design.

Keywords: Aerial additive manufacturing; cementitious materials; pseudoplastic behaviour.

Standardization of low carbon calcined clay cements: the UK experience

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ABSTRACT

Calcined clays are emerging globally as a sustainable alternative to traditional supplementary cementitious materials like fly ash and ground granulated blast furnace slag. In 2019, a UK standard for calcined clays (BS 8615 Specification for pozzolanic materials for use with Portland cement - Natural pozzolana and natural calcined pozzolana) was first published. Amendments to the UK concrete standard (BS 8500 Concrete – Complementary British Standard to BS EN 206) were also subsequently published which, for the first time, included limiting values for the specification of calcined clay cements in concrete. In 2020, the Mineral Products Association (MPA) identified that very little calcined clay concrete was being produced in the UK which was due to a lack of (1) clay calcination plants in the UK and (2) experience/understanding of cements/concretes containing calcined clays, particularly using clays from UK sources. To address these issues a UK consortium led by the MPA began work on developing and testing a new generation of low carbon calcined clay cements and concretes using UK-sourced materials, with a particular focus on using reclaimed materials. In total, 11 reclaimed clay sources from UK sites were selected for investigation – 10 of these have arisen from as overburden materials at UK quarries while one was an already calcined material, arising from a brick manufacturing site. Following an extensive laboratory study on the 10 uncalcined materials, four were selected for pilot calcination using both rotary and flash processes. The calcined brick source was also extensively studied, prior to the completion of a pilot grinding trial. Several tonnes of the new calcined clays were successfully produced with their mineralogy, fineness and pozzolanic reactivity subsequently characterised. An extensive testing programme to validate the performance of newly formulated reclaimed calcined clay cements (Re-C3) and concretes was completed, covering a range of fresh and hardened properties as well as resistance to various exposure conditions. Based on the findings from the project, revisions to BS 8615 and BS 8500 are being prepared to ensure that these UK standards are now up to date, catering for UK-sourced reclaimed materials.

ORAL PRESENTATION
- Hydration
(Session A1)

Hydration characteristics and phase transitions of solid waste in low-carbon cementitious material

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ABSTRACT

A new low-carbon cementitious material (LCCM) was developed using recycled ground blast-furnace slag (GGBS) and clay brick powder (CBP) to reduce the carbon footprint. The hydration characteristics and phase transitions were systematically studied to reveal the interactions among the components in solid waste-based cementitious materials. The results indicate that the disintegration of slag glass requires a significant consumption of highly polar OH^-, which decreases after the reaction initiates. The LCCM containing GGBS exhibits the highest early hydration degree but with a smaller increase after 90 days. In contrast, the early reactivity of CBP is weaker, resulting in lower consumption of calcium hydroxide (CH). However, during the later stage of hydration, CBP continues to consume CH, significantly enhancing the hydration degree of the composite cementitious material. The rapid reaction of GGBS restricts ion diffusion outward, leading to the formation of internal C-A-S-H gel. The varying diffusion rates of ions in GGBS cause the atomic percentages of calcium (Ca) and silicon (Si) to decrease, while magnesium (Mg) and aluminum (Al) increase in the C-A-S-H gel. The disintegration of CBP under the influence of OH^- leads to the outward diffusion of Si and Al, which combine with Ca to form honeycombed C-A-S-H gel in the pore solution. These honeycombed C-A-S-H gels divide and refine the pores, continuously improving the macroscopic mechanical properties of LCCM. The synergistic effect of CBP and GGBS enables the LCCM to achieve a higher initial hydration degree and sustained hydration in the later stage.

Keywords: Low -carbon cementitious material; GGBS; CBP; Hydration characteristics; Phase transitions

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Research on the early cement hydration process in the presence of dispersed nano calcium silicate hydrated (CSH) seeds

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ABSTRACT

For the precast concrete industry, the production efficiency correlated well with the rate of demoulding must be considered priority, which is heavily determined by the growing of compressive strength. And seam curing process is a traditional method for accelerating the progression of cement hydration to satisfy the rapid development of compressive strength. However, steam curing would release significant amount of CO_2 into the atmosphere and cause some adverse effects on the long-term properties. In order to avoid the serious issues caused by the steam curing process, Calcium Silicate Hydrate (CSH) dispersed by comb-like polycarboxylate superplasticizer (PCE), shorted as dispersed nano CSH seed, was utilized to promote the early cement hydration at normal temperature. This investigation aims at disclosing the hydration process of cement and the microstructure evolution of cement paste in the presence of dispersed nano CSH seed during the early stage via setting time, ultrasonic pulse velocity (UPV), compressive strength, conductivity, pH, thermogravimetric (TG), ^{29}Si NMR and nitrogen adsorption/desorption. The results demonstrated that with the dispersed nano CSH seed increasing, the setting process of cement paste was shortened dramatically, the compressive strength and UPV of cement mortar increased significantly especially at 12 h. The variation of conductivity and pH of cement suspension indicated that the ion dissolution process was promoted by dispersed nano CSH seed, which therefore conducive to the precipitation of cement hydration products. TG curves exhibited that the formation of cement hydration products, including CH (Calcium Hydrated), AFt and CSH gel were accelerated by dispersed nano CSH seed. The ^{29}Si NMR (Nuclear Magnetic Resonance) and nitrogen adsorption/desorption results validated that the incorporating dispersed nano CSH seed promoted considerably the polymerization of CSH gel. The aforementioned results are correlated well with the fast formation of microstructure and in turn the rapid development of compressive strength at early age.

Keywords: Cement; Dispersed nano CSH seed; Hydration; Acceleration; Microstructure

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Effect of Ca/Si and Al/S content on hydration behavior of red mud-gypsum based cementitious materials

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ABSTRACT

Red mud (RM) and titanium gypsum (TiG) were combined as waste-derived activators to activate blast furnace slag (BFS) for the preparation of RM-TiG-BFS based cementitious materials (RGB). The study focused on investigating the mechanical properties, hydration products, and microstructure of the resulting RGB. To leverage the synergistic excitation effect of alkali-salt excitation, TiG and RM were mixed in a 2:1 ratio to adjust the content of Ca, Si, Al, and S in RGB. This study investigated the hydration products, microstructure, and mechanical properties of the RM-TiG-BFS (RGB). The findings revealed that incorporating RM and TiG into the mixture enhanced the 3-day and 28-day strengths of RGB, with the compressive strength reaching 63.9 MPa, as long as the Ca/Si ratio remained at or below 2.05 and the Al/S ratio was maintained above 0.7. Furthermore, changes of Ca/Si and Al/S in the system led to reinforce the formation of C(N)-A-S-H gels and AFt crystals as the primary hydration products, thereby improving the microstructure of RGB. This research offered valuable theoretical insights for the utilization of RM, TiG, and other industrial waste materials in the development of advanced building materials.

Keywords: Red mud; Titanium gypsum; Al/S and Ca/Si; Hydration mechanism; Macroscopic properties

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Thermodynamic data and phase equilibria of AFm phases and hydrotalcites containing chloride, bromide, and iodine ions

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ABSTRACT

Cementitious materials present unique advantages for waste immobilization. Layered double hydroxides (LDH) such as AFm and hydrotalcite like phases that form during cement hydration can incorporate a variety of anions in their interlayer positions. This work provides new insights regarding hydrotalcite and/or AFm phase formation in carbonate-free cementitious systems,that may be used in the management of halide-containing liquid wastes. Series of phases of general formula $[M^{II}_{(1-x)}M^{III}_{(x)}(OH)_2][A^{n-}]_{x/n}\cdot zH_2O$ were synthesized, where $M^{II}=Mg^{2+}$(hydrotalcite) or Ca^{2+}(AFm), $M^{III}=Al^{3+}$ such that $[M^{II}/Al]=2$ (Ca and Mg, atomic units) or 3 (Mg only), and $A=Cl^-,Br^-$,or I^-. All phases were characterized to assess their composition and crystal structure. Solubility data of these compounds were obtained at 5, 25, and 60°C and acquired thermodynamic data were integrated into a database to model formation and stability of halide incorporating AFm and hydrotalcite phases in cementitious systems. It was observed that halide-containing hydrotalcite phases strongly compete with hydroxide-containing hydrotalcite, with the latter prevailing at high pH. In contrast, halide-containing AFm compounds are more stable as compared with hydroxide-containing AFm phases.

Keywords: AFm; Hydrotalcite; Equilibrium constant; Thermodynamics; LDH

The influence of municipal solid waste incineration bottom ash on Portland cement hydration and binder properties

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ABSTRACT

By 2012, around 1.3 billion tons of municipal solid waste incineration bottom ash (MSWIBA) had accumulated globally, and with new waste-to-energy plants, it is expected to reach 2.2 billion tons by 2025. While MSWIBA is typically stored in landfills, there is a growing interest in using it in the construction of road pavements and, more importantly, in cement-based materials widely used in construction. The chemical composition of the MSWIBA landfilled for 6 and 18 months turned out to be quite stable. The amount of gamma radionuclides identified in MSWIBA meets the requirements of hygiene norms, thus proving that bottom ash from municipal incinerator can be used without any restrictions. The aim of this work is to analyse the influence of MSWIBA on cement hydration when bottom ash content in the mixture is 60%, and develop a binder suitable for road building. This work investigates the procedure of milled MSWIBA preparation for the road binder and calorimetric, thermogravimetric, X-ray Rietveld, as well as physical and mechanical properties of the binder. The rapid hardening hydraulic road binder with compressive strength of approximately 10 MPa after 7 days and 20 MPa after 28 days meets the requirements of EN 13282-1 for the E2 strength class. The main component of this binder is 60% MSWIBA. The addition of 5% quicklime reduces the destructive effects of metallic aluminium, which is inevitably present even in the treated MSWIBA and causes swelling of the hydrating cementitious binders. The amount of amorphous binder phase compared to control samples after 28 days increased about 50%, however, the amount of portlandite decreased about 8 times. The enthalpy at the portlandite decomposition temperature decreased about 10 times. The control sample had a cumulative heat release value of 273 J/g, whereas the road binder with 60% MSWIBA released 174 J/g.

Keywords: Municipal solid waste incineration bottom ash; Road binder; Cement hydration; Density, Compressive strength

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Comprehensive study the macroscopic properties, hydration-carbonation process and micropore structure of natural hydraulic lime-based materials prepared with metakaolin as mineral admixtures

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ABSTRACT

The issue of slow early setting and strength development is a common problem faced by natural hydraulic lime (NHL) in both historic building restoration projects and modern construction. This study aims to reveal the phase composition and microstructure of natural hydraulic lime-based materials modified by metakaolin and its effect by natural carbonation. The results demonstrate that metakaolin could promotes the setting times of NHL, and generally exhibits a significant enhancement effect on the mechanical strength. Additionally, the drying shrinkage of NHL mortar can be effectively reduced by adding 10% metakaolin. In terms of hydration products, C4AĈH11 and C-S-H are identified as primary products during the early stages for M-NHL mortars, along with other hydration products such as C-A-(S)-H being formed later on. At longer ages, the carbonation reactions occur primarily with C-S-H and C-A-(S)-H phases, while decomposition or transformation into other phases is more likely for C4AĈH11. Interestingly, when M-NHL mortars with 10% metakaolin, it not only promotes early hydration but also enhances long-term carbonation processes. The significant carbon dioxide uptake effect (~20% wt.%) is also found significant, and the low carbon effect in the whole life cycle means that M-NHL is environmental-friendly materials. The pozzolanic effect induced by metakaolin that reduces macropores and refines pore size within M-NHL system, which helps maintain high pore connectivity coefficient as well as effective porosity, and more effective pathways conducive to inward transportation of CO_2 gas, thereby promote the carbonation process.

Keywords: Natural hydraulic lime; Metakaolin; Natural carbonation; Hydration product; Microporous structure

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ORAL PRESENTATION
- Novel cementitious materials
(Session B1)

Understanding the behaviour of magnesium potassium phosphate cement under alkaline environment

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ABSTRACT

Magnesium potassium phosphate cements (MKPCs) are formed through an acid-base reaction between MgO and potassium dihydrogen phosphate (KH_2PO_4). When the reactants are in equimolar amounts, K-struvite ($MgKPO_4.6H_2O$) is the main mineral formed during hydration and the pore solution pH is close to 8. Information on the long-term evolution of MKPC-based materials is still limited, especially under the alkaline conditions that may be encountered in the near field of a conventional concrete produced with Portland cement (PC). In this work, two complementary configurations are investigated: MKPC paste *(i)* in close contact with PC paste, or *(ii)* leached by an alkaline solution mimicking the pore solution of the PC paste.

MKPC (Mg/P molar ratio = 1) and PC pastes were prepared at a water-to-cement ratio of 0.51 and 0.4, respectively, and cured under endogenous conditions at 20°C for 23 d or 180 d. For the MKPC/PC paste interface study *(i)*, two cylindrical samples were initially resaturated with their own synthetic pore solutions and maintained confined in a Hoek cell for 3 months. For the leaching study *(ii)*, semi-dynamic leaching tests were carried out for 14 d and 170 d on MKPC monoliths using an alkaline solution which was periodically renewed to avoid accumulation of dissolved species. Leachates were analysed by ICP-AES. In both kinds of experiments, post-mortem characterization of the solids was performed using XRD and SEM/EDS analyses.

Leaching induced a decrease in the content of crystalline K-struvite, as well as the precipitation of Ca-deficient hydroxyapatite (CDHA), brucite and possibly magnesium silicate and aluminate hydrates. A thin layer of a phosphate mineral also formed at the MKPC/PC paste interface and could explain the good bonding between these two materials.

Keywords: Magnesium phosphate cement; Portland cement; Durability; Phase evolution; Leaching

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Sulphosilicate cement

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ABSTRACT

Sulphosilicate cement (SSC) is a new type of low-carbon cement which is further based on the mineral composition of BCSA clinker but incorporation of $C_5S_2\$$. The thermal decomposition characteristics of $C_5S_2\$$ determine that the sintering temperature of SSC is usually about 250 °C lower than that of PC and more than 100 °C lower than that of CSA. In addition, due to the lower CaO content in SSC, its CO_2 emission during sintering is usually reduced by about 63% compared to PC and 46% compared to BCSA. Low CaO content creates low-carbon characteristics, and more importantly reduces the high demand on high grade materials for clinker manufacturing, which can make use of industrial wastes. $C_5S_2\$$ was once considered to be an “inert” mineral, but it is worth pointing out that $C_5S_2\$$ can show stronger hydration activity than C_2S in sulphoaluminate system. This unique characteristic endues SSC with rapid development of mechanical properties at early stage, and steady growth of strength at middle and late stages, showing good strength performance. SSC materials demonstrate good durability as well.

Keywords: Durability; Low-carbon cement; Performance; Sulphosilicate cement

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Characterization and performance of BCSA concrete in the field for 30 years

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ABSTRACT

Belitic Calcium Sulfoaluminate (BCSA) is sometimes discussed as a recent development in low-carbon cements. However, it was first developed and placed as concrete in the United States in the early eighties. BCSA is a low-carbon cement with additional benefits such as fast setting behavior, high early-age strength, low shrinkage, resistance to chemical attack, and long- term durability.

This report discusses the analyses of the mechanical properties, microstructure, and chemical composition of BCSA concretes used in highway and airfield pavements in several climates on the United States West Coast. The report describes some characteristics of BCSA concrete samples obtained from the Seattle International Airport, the Burbank Airport, and Interstate 10 in Los Angeles. The three projects were built in the mid-to-late 1990s and have been in service ever since. These results are significant because while many low-carbon cement concretes are being developed, few, if any, have been manufactured in quantities large enough for placement in the field, have obtained specification approvals, have developed environmental product declarations (EPD), or have been in service for over 30 years. It was observed that the long-term performance of this concrete shows no significant signs of reduced performance or deterioration.

Evidence shows that BCSA cements are a durable, rapid-setting, and low-embodied carbon concrete alternative that can be used as the paving industry transitions towards alternatives with lower global warming potential (GWP).

Keywords: Belitic Calcium Sulfoaluminate, Low-carbon cement and concrete

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Cement based ductile rapid repair material modified with self-emulsifying waterborne epoxy

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ABSTRACT

Ordinary silicate cement repair materials have slow setting, low early strength, and cannot meet rapid repair demands, with obvious post-repair brittleness. Calcium sulfoaluminate cement (CSA) is better suited for rapid repairs due to fast hardening and early strength, but still suffers low bond strength and poor toughness. Recently, polymer-modified cementitious materials have attracted attention for repair and reinforcement. Among polymers, epoxy resins show excellent cement hydration compatibility and coupling effects, making them a promising choice. This study prepared a waterborne epoxy resin (WEP) modified CSA cement composite repair material (CEP) and elucidated the mechanism of WEP's performance improvements. Results showed adjustable workability by modifying WEP content. WEP significantly improved interfacial bond strength. With 10% WEP, CSA cement repair material toughness increased 32.2% and tensile ductility 93.8% versus control. Fully cured WEP and CSA cement hydration products formed a dense crosslinked network refining the pore structure and improving the high brittleness and low ductility disadvantages of the repair material. In summary, WEP improves CSA cement repair material workability, bond strength, and toughness by forming a dense crosslinked network with CSA hydration products that refines the pore structure. This addresses high brittleness and low ductility issues facing rapid repair materials.

Keywords: CSA cement; Rapid repair materials; Water-based epoxy resins; Bond strength; Pore structure

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Calcium sulfoaluminate cements for the encapsulation of ion exchange resins for nuclear applications

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ABSTRACT

Calcium sulfoaluminate (CSA) cement systems have been identified as a promising alternative to the current UK baseline technology of Portland cement (PC) based systems for the encapsulation of problematic intermediate level wastes (ILW). Their unique chemistry offers improvements in waste-cement interactions with the potential to reduce waste corrosion, either due to a lower pore solution pH or chemical binding of a large proportion of mix water in hydration products. In addition, highly fluid grouts can be produced from CSA formulations offering enhanced penetrability of wastes and mixing of viscous wastes. Optimum CSA formulations have been identified following small scale trials (≤3 L) for subsequent waste matrix interaction studies. The studies presented in this paper investigate the ability of three CSA formulations to encapsulate an inactive surrogate inorganic ion exchange resin, clinoptilolite, at 43 vol% waste loading using an in-drum mixing technique. The results show that the CSA formulations can successfully accommodate a fully saturated 'surface dry' clinoptilolite test material at ~43 vol% loading with improved rheology, strengths, and dimensional stability compared to typical PC based systems. All CSA formulations achieved final set in <24 h and produced cumulative heats of hydration at 24 h greater than that of a typical PC based system. This coincided with accelerated initial set times for the CSA formulations.

Keywords: Calcium Sulfoaluminate Cements; Clinoptilolite; In-Drum Mixing; Processing Properties; Product Quality; Nuclear Applications

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Preparation and properties of Portland cement clinker by high magnesium limestone

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ABSTRACT

Cement is a widely utilized material in the construction industry, with Ordinary Portland Cement (OPC) being one of the most commonly used varieties. As science and technology continue to advance, cement production has increased significantly, leading to substantial consumption of high-quality ore resources for cement clinker preparation. Additionally, the accumulation of low-grade raw materials and industrial waste contributes to environmental pollution and resource scarcity. Therefore, utilizing low-grade raw materials and industrial wastes for cement clinker preparation represents an effective solution.

This study focuses on using high magnesium limestone and iron tailings to prepare Portland cement clinker while considering the quantity of high magnesium limestone used as well as the role played by iron tailings. The mineral composition of cement clinker and the strength of cement slurry are analyzed in order to produce qualified Portland cement clinker.

Keywords: Portland cement clinker; Iron tailings; High magnesium limestone

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ORAL PRESENTATION
- SCMs
(Session C1)

Efficient utilization of cementitious materials to produce sustainable blended cement

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ABSTRACT

To achieve sustainable development of cement industry, cementitious efficiency of different cement clinker and supplementary cementitious materials (SCMs) fractions, in terms of hydration process and strength contribution ratio, was characterized. The results show that blast furnace slag and steel slag should preferably be arranged in fine fractions due to their desirable hydration processes and high strength contribution ratios. Cement clinker should be positioned in intermediate fraction (8–24 μm) due to its proper hydration process. Replacement of cement clinker by SCMs with low activity or inert fillers in coarse fractions was also suggested, because coarse cement clinker fractions gave very low hydration degrees and little strength contribution. Both early and late properties of gap-graded blended cements prepared can be comparable with or higher than those of Portland cement, indicating both cement clinker and SCMs were used more efficiently. These blended cements also give additional cost savings and reduced environmental impact.

Keywords: Size fraction; Supplementary cementitious materials; Blended cement; Strength contribution; Hydration degree

From bauxite residues to new sustainable SCM

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ABSTRACT

The European project “ReActiv” proposes a novel sustainable symbiotic relationship between two industrial sectors, the alumina production industry and the cement production industry, by transforming Bauxite Residue from industrial waste to a new Supplementary Cementitious Material or SCM, thus reducing both wastes and CO_2 emissions respectively. In this manner, ReActiv creates a win-win scenario of excellence for both industrial sectors.

The present paper focuses on 2 innovative and reductive fusion processes in pilot facilities for producing such reactive bauxite residue based-SCMs. The first one is based on a vitrification process at 1250-1300°C to produce an iron-rich vitrified slag. The second one is based on a smelting process at 1500°C with the objective to produce metallic iron from on hand and an iron-free granulated slag from the other hand. The efficiency of processes is validated by the chemical and mineralogical analyses showing, for the vitrification one, an equilibrated chemistry that allows fusion at around 1250°C and, for the smelting one, a huge decrease in iron content and above 70% of glassy phase. The reactivity of the 2 slags produced from each route is then assessed both with the R^3 calorimeter tests as well as in cement formulations (30% replacement rate) with EN standard mechanical strength measurements. The results obtained have shown good reactivity, especially at early age.

Keywords: Blended cement; Bauxite residue; Melting; CO_2

Study on the influence of silica fume on steel slag cement-based materials

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ABSTRACT

Due to high permeability, high activity and excellent functionality of nanomaterials, they can be used as new surface treatment agents to improve the performance of cement-based materials while imparting functionality (such as self-cleaning, air purification, bacteriostatic and electromagnetic shielding). However, most of the nanomaterials are directly applied to the surface of cement-based materials, and their poor adhesion to the substrate results in poor durability. Nanomaterials with pozzolanic activity, such as nano-SiO_2, can undergo pozzolanic reactions with the matrix. Using this feature, it is combined with functional nanomaterials to improve the performance of cement-based materials, impart functionality, and enhance the durability of nanomaterials. This study focuses on nano-SiO_2, functional nanomaterials (such as wave-absorbing and photocatalytic nanomaterials) and their composite materials to treat the surface layer of cement-based materials, studying its effects on the properties, functionality and durability of cement-based materials. Under the induction of magnetic field, the excellent magnetic properties of Fe_3O_4 nanomaterials can be used to penetrate the surface of cement-based materials. The SiO_2 shell can improve the dispersibility, oxidation resistance and wave absorption of Fe_3O_4 nanomaterials. The sample treated with the Fe_3O_4@SiO_2 core-shell nanomaterials has a small reflectivity and is less reflective than the pure Fe_3O_4 treated sample. Some nanomaterials with core-shell structure, such as TiO_2@SiO_2, SiO_2@TiO_2 and BiOBr@SiO_2, were prepared. The nanocomposites were applied to the surface of cement-based materials to test the photocatalytic effects of direct treatment, curing and rain simulation. SiO_2 shells can effectively stabilize the photocatalyst. The research provides a technical approach for the functionalization of cement-based materials, providing theoretical basis and support for the design and application of other similar structures.

Keywords: Surface treatment; Cement-based materials; Nanomaterials; Composite materials; Functionalization

Preparation of SO_4-AFm and its effect on heavy metal solidification of red mud-graphite slag based subgrade materials

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ABSTRACT

Red mud and graphite slag as important constituents of solid wastes have recently been developed as subgrade materials. Ensuring the harmlessness of such newly-developed red mud-graphite slag based subgrades in terms of heavy metal leaching is significantly essential before their wide utilization. In this study, SO_4-AFm was synthesized via co-precipitation and hydrothermal method in alkaline environment. The effects of alkaline species and reaction time were studied. The transformation of ettringite to SO_4-AFm was investigated via XRD, IR and SEM. Subsequently, the effect of as-prepared SO_4-AFm on immobilizing heavy metals in red mud-graphite slag based subgrade materials were evaluated. The evolution of electric conductivity and leaching features were monitored under simulated acid rain and aqueous condition. Results showed that sodium ions drastically induced the transformation of ettringite to SO_4-AFm due to the formation of U-phase. Extension of reaction time resulted in transition of U-phase to SO_4-AFm with 16h as the optimal reacting time acquired. Meanwhile, SO_4-AFm performed remarkable immobilization on heavy metals in red mud-graphite slag based subgrades with a noticeable decline in electric conductivity gained. Comparably, the leaching of heavy metals was less under aqueous conditions that in acidic environments, suggesting better heavy metal stability in mild solutions. Meanwhile, SO_4-AFm exhibited superior immobilization on elements of Pb and Cu in both acidic and aqueous environment with the leaching amount reduced by 100% and 60%, respectively. It could also be effective for the leaching hindrance of As under simulated acid rain. However, there was rare improvement on the immobilization of Cr. It is therefore anticipated that it has guiding significance for the formation of SO_4-AFm and the solidification of heavy metals in solid waste-based materials.

Keywords: SO_4-AFm; Synthesis; Heavy metal; Immobilization; Solid-waste based subgrade materials

The role of pozzolanic building materials – A time lapse from Roman times to the future

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ABSTRACT

Natural pozzolans have been used in building construction for more than two millennia due to their high mechanical and durable behaviour. The invention of Portland cement and the subsequent enormous production development in the 19th century led to a certain displacement of traditional pozzolans, but it quickly became apparent that the combination of Portland cement clinker with natural and artificial pozzolans offers many advantages. In particular, the production of cement clinker has always been energy-intensive and, therefore, alternative constituents exhibiting a certain reactivity, today known as supplementary cementitious material (SCM), were used early on in the production of modern cements. However, the global use of SCMs has always been very different due to their availability. In the past, pozzolana cement production was mostly limited to countries with natural availability of pozzolanic rocks (e.g. Italy, Turkey, Greece, Philippines). In other countries that do not have these natural resources (e.g. United Kingdom, Germany) it was possible to use by-products from other industries, in particular steel production (blast-furnace slag) and coal-fired power plants (fly ash), as SCM. However, due to the industrial structural change, artificial SCMs will no longer be available in sufficient quantities in the future. Additionally, the cement industry has increasingly taken on the responsibility of reducing its carbon dioxide emissions, which has led to a renaissance in the use of natural materials that not only allow the proportion of cement clinker to be reduced, but can even use carbon dioxide as an activator. This challenge also means a rethinking of the composition of cements according to today's cement standard EN 197. The use of calcined clays, for example, can help to reduce the clinker content in cement, but in the long term it makes sense to consider naturally occurring materials such as olivine or similar, which can be used in cement production without significant modifications. Reinvent the concept of pozzolanic activity by looking for new way of processing natural materials solutions are also is currently target of many innovators active in the field of cement and concrete, however it seem that a wide exploitation of this technologies is still far and we will have to deal with the traditional and cost effective natural pozzolan for long time This article reviews the latest research on natural pozzolanic cement and the possible future opportunities brought by this very traditional and long-used building material.

Keywords: Pozzolan; Supplementary cementitious materials; Natural SCM; Activated SCM; Carbon dioxide

Investigation on the chloride binding behavior of low-carbon cementitious materials containing waste clay brick powder

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ABSTRACT

Due to the pozzolanic activity and low grinding energy consumption, waste clay brick powder (WCBP) has shown promising potential for use as supplementary cementitious materials (SCMs). Understanding the chloride binding behavior of cement paste is critical for mitigating steel corrosion and averting deterioration in concrete structures. This study investigated the effect of WCBP on the chloride binding behavior of blended cement pastes. Blended cement pastes prepared with a reference Portland cement and composite Portland cements containing WCBP were exposed to NaCl or $MgCl_2$ solutions. The chloride binding isotherms, pH change, and hydrate assemblage were investigated using XRD, TGA, and SEM-EDS. The results revealed that for all pastes, more chlorides were bound in samples exposed to $MgCl_2$ solutions than NaCl solutions. Notably, the incorporation of WCBP could improve the chemical chloride binding capacity because of the increasing generation of Friedel's salt. However, the excessive addition of WCBP decreased the total chloride binding amount. Furthermore, the WCBP replacement resulted in a lower Ca/Si ratio of C-(A)-S-H gels, leading to a weaker physical chloride binding capacity. These findings offer novel insights into the influences of WCBP on the chloride binding behavior of cementitious materials.

Keywords: Waste clay brick powder; Low-carbon cementitious materials; Chloride binding; Hydrate assemblage; Friedel's salt

ORAL PRESENTATION
- Emerging technology 1
(Session A2)

How to reliably assess the embodied carbon of concrete?

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ABSTRACT

Concrete and cement production account for approximately 8% of global carbon dioxide emissions. Therefore, the need to develop lower carbon concrete technologies has become more relevant than ever, given the ambition to decarbonise concrete and construction in the next decades. As a result, several concrete technologies have emerged, and existing ones are being deployed more widely. There is, however, lack of definitions for low carbon, sustainable, and eco-friendly concrete which can lead to confusion within the industry making it hard to enable an objective inter-technology comparison in terms of embodied carbon. For this reason, embodied carbon classification systems are under development to establish shared definitions and rules for classifying and communicating the cradle-to-gate embodied carbon of concrete, which can be used as a basis for policies and tools for specification towards concrete decarbonisation. Nevertheless, these systems come with peculiarities and limitations on their applicability. In this paper some of these systems are reviewed and recommendations are provided with respect to systems limitations and future applications. This will provide guidance as to where classification systems are applicable and how the embodied carbon of concrete can be reliably assessed.

Keywords: Concrete, Embodied carbon, Classification

An evaluation method for the printability of magnesium phosphate cement concrete for integrated mixing-stirring-extrusion rapid 3d printing

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ABSTRACT

This study examines a new 3D printing molding process for Magnesium Phosphate Cement (MPC) based materials. The process involves inputting dry powder and outputting wet material. The study proposes an evaluation method for the integrated 3D printer with functions of mixing, stirring, and extrusion for rapid setting concrete is used for the research. The study proposes an evaluation method for the printability of materials based on the consistency of MPC paste measured by a Vicat apparatus. The study systematically examines extrudability, buildability of MPC concrete extruded by the 3D print head under different water-to-material ratios (mass ratio of water to dry mix). The results show that the extrusion consistency is between 25-34 mm, the 3D printed MPC concrete exhibits good extrudability, and when the extrusion consistency is between 23-34 mm, the 3D printed MPC concrete shows excellent buildability. Therefore, the Vicat consistency could be used as an evaluation method for the printability of rapid-setting materials in the rapid-setting and hardening MPC-based material 3D printing process. When the extrusion consistency of MPC paste is in the range of 25-34 mm, the integrated mixing-stirring-extrusion 3D printing molding process for MPC-based materials can be realized. This method simplifies the operation process and procedures of the 3D printing equipment, ensuring accurate shaping and stability of performance of the 3D printed cement-based materials.

Keywords: Fast 3D printing; Magnesium phosphate cement concrete; Printability evaluation method; Consistency

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Development of CO_2-integrated 3D concrete printing

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ABSTRACT

To meet the demanding requirements of pumpability and buildability inherent in 3D printing, the rheological properties of mortar/concrete must adhere to stricter standards compared to traditional casting methods. This study proposed a novel approach utilizing secondary CO_2 mixing alongside the incorporation of silica fume (SF) to achieve precise in-situ control of rheology in 3D-printed mortar. The research investigated the effects of CO_2 mixing on both cast mortar and 3D-printed mortar prepared with SF. Chemical analyses including pH, conductivity, and ion concentration were conducted to elucidate the chemical reactions and phase transformations occurring during CO_2 mixing. The findings demonstrated that CO_2 mixing significantly enhances the early-age penetration resistance and yield stress of SF-incorporated mortar, thereby substantially improving the buildability of 3D-printed mortar, enabling an increase in the maximum printing layer by over 33 layers. Moreover, the mechanical properties of SF-incorporated mortar were enhanced through this process. The study revealed that during CO_2 mixing, the injected CO_2 rapidly reacted with calcium ions to form $CaCO_3$, which further reacted with C_3A to produce monocarboaluminate (Mc). This rapid precipitation of calcium ions accelerated the hydration of key cement compounds (C_3A and C_3S), leading to early strength development and improved performance of hardened mortar. Furthermore, the addition of SF amplified the beneficial effects of CO_2 mixing, acting as nucleation sites that promote the formation of $CaCO_3$ and Mc during the CO_2 mixing process. This synergistic interaction enhanced the overall performance of the mortar, underscoring the effectiveness of the proposed approach for enhancing the properties of 3D-printed structures.

Keywords: 3D printed mortar; CO_2 mixing; Silica fume; Buildability; Rheology

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Triaxial compression behaviour of microcapsule-based self-healing concrete

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ABSTRACT

Microcapsule-based self-healing concrete can autonomously release repairing agents to bond and seal cracks when the material is damaged. It is seen as a promising construction material from the perspective of a sustainable society. It is essential to study mechanical behaviour under complex stress conditions to promote the application of self-healing concrete in engineering structures. Accordingly, this study investigated the mechanical behaviour of microcapsule-based self-healing concrete under uniaxial and triaxial compression states. The self-healing concrete was prepared by mixing different dosages of epoxy/urea-formaldehyde microcapsules. The effect of confinement pressure, considerable axial strain, and microcapsule dosage on the mechanical behaviour of the self-healing concrete was investigated through uniaxial compression, conventional triaxial compression, true triaxial compression, and the mercury intrusion porosimetry (MIP) test. The constitutive relations, strength and deformation, and failure criterion were determined. The results show that incorporating microcapsules reduced the cohesive strength and internal friction angle of the concrete. The influence of microcapsule dosage on triaxial strength was rapidly weakened with increasing confinement pressure. Both the incorporation of microcapsules and the application of confinement pressure can improve the plastic deformation capacity and reduce the brittleness of the specimens. The multi-crack failure mode allowed more core material in the form of microcapsules to enter the microcracks, which accordingly increased the strength of the microcapsule-based concrete.

Keywords: Microcapsules; Self-healing concrete; Triaxial test; Pore structure; Failure criterion

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ORAL PRESENTATION
- Emerging technology 2
(Session B2)

Feasibility of long-distance transportation of concrete based on liquid nitrogen freezing

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ABSTRACT

Concrete freezing has always been opposed in the concrete industry. However, using an appropriate freezing method can open up more applications for concrete and compensate for the limitations of concrete transportation distance. This paper explores the use of liquid nitrogen for quick-freezing of fresh cement mortar, followed by mechanical tests and microscopic analysis after scientific thawing. The paper discusses the control of freezing rate on the performance of frozen concrete blocks and the application prospects of frozen concrete blocks. The results indicate that quick-freezing technology has minimal and negligible impact on concrete, making it applicable in the field of concrete.

Keywords: Concrete freezing, Quick-freezing, Liquid nitrogen, Concrete transportation

Encapsulation of SIERs in MKPC cements

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ABSTRACT

Magnesium phosphate cements (MKPCs) are positioning as good candidates for the immobilisation of low and intermediate radioactive waste. These cements set and harden via acid-base reaction between a MgO and a KH_2PO_4, to form as main reaction product K-Struvite. Among its advantages, include the rapid strength development at early ages, good volume stability and low water demand.

The present work explores the effect of incorporating spent ion exchange resins (SIERs), doped with Cs, in magnesium phosphate cements (MKPC), prepared with a low-grade MgO (~58 % MgO). For this purpose, different proportions of the Cs-doped resin (0, 10, 15 and 20 wt.%) were added into MKPC pastes (prepared with an M/P molar ratio of 3). At different time intervals (1, 7 and 28d), compressive strengths were tested. The effect of resins on the kinetic of reaction, the mineralogy (XRD) and the microstructure (MIP, BSEM /EDX) were also determined.

The results obtained show that the incorporation of resins retards the kinetic of reaction, decreases the mechanical strength development and affects the microstructure (increasing the total porosity values). However, all systems, including those with the highest proportion of SIERs (20%), overpass the 10 MPa (waste acceptance criteria) after 28 days of curing. The presence of resin does not seem to affect formation of K-Struvite.

Keywords: MKPC; Low grade MgO; Encapsulation; Spent ion exchange resins (SIERs); K-struvite

Chlorellestadite: an APT binder or an SCM with carbonation reactivity

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ABSTRACT

Chlorellestadite (ideal formula of $Ca_{10}(SiO_4)_3(SO_4)_3Cl_2$, CE) is an intermediate mineral that forms during the fabrication of Portland cement or ecological clinkers from solid wastes containing both sulfate and chlorine. Due to its water-insolubility, CE presents challenges for application in typical construction practices. To indirectly promote the use of chlorine and sulfate-containing waste as feedstock in cement production, this work investigated the viability of employing CE as a binder or an SCM under a binary curing system of carbonation and hydration. Results showed that CE had carbonation reactivity, enabling the sequestration of 4.8% (by mass) of CO_2 and the development of a compressive strength of 25.8 MPa after undergoing 24 hours of carbonation curing with $CaCO_3$, $CaSO_4$, $CaCl_2$, and silica gel as carbonation products. Substituting 20 wt% CE in dry-cast pastes (CE20) resulted in a reduction in 1d compressive strength due to the decreased cement content. However, carbonation of CE introduced secondary gypsum into the binder system, promoting the formation of an additional AFt phase within pores during subsequent water curing. Consequently, the 28d strength of CE20 (93.4 MPa) surpassed the OPC reference by 21.1%. These findings underscore not only the potential of using CE as a binder or an SCM in dry-cast non-structural concrete but also the feasibility of utilizing waste materials containing sulfate and chlorine as feedstock for synthesis, thereby mitigating environmental risk associated with such wastes.

Keywords: Chlorellestadite; Carbonation reactivity; Binder; Supplementary cementitious material; Solid waste

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Investigation on improving toughness of steamed concrete by using rubber particles or fibers

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ABSTRACT

Nowadays, steam curing is widely used in the production of prefabricated components. However, steam curing system may cause micro cracks in concrete, resulting in brittleness and easy cracking. In order to improve the toughness of steamed concrete, rubber particles and steel fibers are added into steamed concrete. The influence of rubber particles and steel fibers on flexural performance of steamed concrete were studied using a combination of digital image technology (DIC) and acoustic emission technology (AE). The impact resistance of steamed concrete was investigated using the Hopkinson's Pressed Bar Test (SHPB). The effects of rubber and steel fibres on the peak stress, dynamic modulus of elasticity, dynamic influence factor, impact toughness, and the degree of impact damage of steamed concrete were investigated. The finite element method (FEM) was used to explain the influence of rubber particles on the impact performance of steam-cured concrete. The research results show that the addition of steel fiber increases the number of damage sources by more than 40 times. Rubber particles significantly improve the impact toughness index of steam-cured concrete, and the peak toughness is the largest when the rubber dosage is 70kg/m^3. The simulation results were consistent with the dynamic test data for visualising the crack development process of concrete under high-speed impact loading

Keywords: Steamed concrete; Rubber particles; Steel fibers; Hopkinson's Pressed Bar Test (SHPB)

ORAL PRESENTATION
- Alkali-activated materials 1
(Session C2)

Confirmation of control impact on hydration reaction of alkaline activated slag

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ABSTRACT

The exothermic reaction of alkaline activated slag (AAS) is influenced by the type of alkaline activator used. When using a NaOH-based activator, there are two main exothermic peaks, whereas three exothermic peaks are observed with a sodium silicate-based activator. To compare the hydration mechanisms of these two systems, mono-, di-, and triethanolamine (MEA, DEA, and TEA) were added individually as diluents to the activators to enhance the changes during the hydration process. The results of the hydration exothermic reactions show contrasting patterns. In NaOH-based AAS, TEA caused the most significant retardation, while MEA had the least impact. However, in sodium silicate-based AAS, TEA had the weakest effect, and MEA had the strongest. Mineral analysis and SEM images revealed that MEA and DEA only slowed down the entire hydration process, while TEA notably altered the product formation process and distributions, resulting in the formation of ettringite mineral nests and decreasing the strength after 28 days. Further quantitative analysis indicated that the control impact of the hydration reaction in NaOH-based AAS is the saturated concentration of Ca^{2+}, Al^{3+}, and other cations. In contrast, for sodium silicate-based AAS, the control impact is the diffusion rate of the silicate ion from the bulk pore solution to the interface on slag particles, while these ethanolamines exhibit a mass action law for the retardation.

Keywords: Alkaline activated slag; Ethanolamine; Hydration heat; Hydration mechanism

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Understanding the internal curing process in alkali-activated slag paste with SAP by low-field nuclear magnetic resonance

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ABSTRACT

Superabsorbent polymer (SAP) has been widely utilised to mitigate the autogenous shrinkage of alkali-activated slag (AAS) pastes through internal curing. The effectiveness of the internal curing strategy is considerably affected by the concentration of activator used in the AAS pastes, as this alters both the reaction process and the absorption behaviour of SAP particles. However, the combined impact of these factors on the internal curing process in AAS with SAP has been not well understood in the literature. This paper presents a preliminary investigation into the absorption behaviour of the SAP particles and the reaction process in the AAS pastes with different silicate moduli through the ^{1}H nuclear magnetic resonance characterisation. The effects of these variations on the autogenous shrinkage of AAS pastes are then analysed and discussed. The results show that increasing the silicate modulus accelerates the initial reaction, consuming more activator and leaving less activator for internal curing. This subsequently reduces the internal curing effectiveness, contributing to an increase in self-desiccation-induced autogenous shrinkage. Moreover, the faster reaction tends to enhance the reaction degree and contributes to the development of non-desiccation-induced autogenous shrinkage. In summary, this study contributes to understanding the internal curing-based strategy to mitigate autogenous shrinkage of AAS pastes.

Keywords: Alkali-activated slag; Autogenous shrinkage; Internal curing; Superabsorbent polymer; Silicate modulus

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Carbonation of clinkering-free fly ash paste

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ABSTRACT

Concrete is the second most consumable material on the planet only behind water. The production of the principal ingredient (i.e., cement), contributes to 5–7% of annual global CO_2 emissions. To create alternatives to this CO_2-intensive process, this project developed a new technology of clinker-free cementation by the carbonation of fly ash. (i.e., a by-product of coal combustion). The samples were customized and cured in a designed CO_2 curing chamber to investigate the carbonation behavior, microstructure, and strength development of fly ash pastes in different depths by using TG, BSEM, XRD, Nano-indentation, and NMR technologies. Meanwhile, the roles of CO_2 concentration, reality humidity, and processing temperature in the carbonation process were discussed. The outcomes created new pathways for achieving clinking-free cementation while enabling the CO_2 capture and utilization fly ash.

Keywords: CO_2 curing; Low carbon concrete; Carbon neutral; Fly ash; Cement hydration chemistry

Preparation of carbon fibers / multiple solid waste geopolymer-based composites and its electrothermal properties

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ABSTRACT

The development of low-carbon cement is an important opportunity and a great challenge in the field of building materials. At the same time, with the advancement of urbanization and industrialization, a large number of solid waste is produced, which not only brings serious environmental problems, but also causes a huge waste of resources. The use of industrial solid waste to produce low-carbon building materials has attracted increasing attention from researchers. In this study, several industrial solid wastes, including phosphate gypsum (PG), slag powder (SP) and steel slag powder (SSP), were used as the main raw materials to prepare the geopolymer. Shortcut carbon fibers was introduced into the geopolymer to obtain the carbon fiber/multiple industrial solid waste geopolymer based composites (CGCs). The obtained CGCs exhibited excellent electro-thermal performance and stable heating cyclic properties. The average surface temperature of the composites is approximate to outstanding 170 ℃ under 9 V with uniform heat distribution. Geopolymers have the advantages of high temperature and fire resistance, so polymer-based composites have great potential in thermal work scenarios. The results of this study indicate that the CGCs has an application prospect in including indoor heating, and pavement snow melting and deicing, which greatly broadens the application field of solid wastes geopolymer-based composites.

Keywords: Geopolymer; Solid waste; Phosphate gypsum; Resistance; Electro-thermal performance

ORAL PRESENTATION
- Carbonation & Decarbonisation 1
(Session A3)

Preparation of carbon-negative artificial lightweight aggregates by carbonating sintered red mud (SRM): CO_2 sequestration, microstructure and performance

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ABSTRACT

To efficiently utilize the low-value sintering red mud waste (SRM) on a large scale, a CO_2 curing method was proposed for the activation of cement-free SRM artificial aggregates. The effects of different curing methods (CO_2 and air curing) and varying fly ash (FA) dosages on the properties of SRM artificial aggregates were explored. In the case of SRM artificial aggregates subjected to CO_2 curing, the calcium silicates depleted accompanied by the precipitation of calcite and aragonite. The carbonated SRM artificial aggregates exhibited a denser microstructure, with the pores of the SRM itself filled with carbonation products. For carbonated artificial aggregates composed entirely of SRM, up to 10.07 wt.% CO_2 was sequestered and in turn produced calcium carbonate, which resulted in a 149.0% enhancement in crushing strength and a 29.5 % reduction in water absorption compared to the similar aggregate under air curing. The introduction of FA led to an accelerated strength development in the carbonated artificial aggregates during subsequent air curing, attributed to the hydration between the carbonation products $CaCO_3$ and aluminates derived from FA to form carboaluminates. From an environmental perspective, carbonated SRM artificial aggregates was carbon-negative, presenting a cleaner and sustainable alternative to natural aggregates. The results of the study provided a feasible solution for the effective treatment of SRM on a large scale and can be used as a reference for subsequent studies.

Keywords: Red mud; Artificial lightweight aggregates; CO_2 curing; CO_2 sequestration; Microstructure

Controlling hydration and carbonation of reactive MgO with amino acids

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ABSTRACT

Portland cement (PC) production is accountable for 8% of anthropogenic carbon dioxide (CO_2) emissions. The concrete and construction industries have been under increasing pressure to develop alternative binders and technologies that produce fewer CO_2 emissions, resulting in an increased interest in sustainable practices. Compared to CaO (responsible for 60-70 wt.% cement clinker), reactive MgO (RM) from calcining $MgCO_3$ has a lower calcination temperature (700–900 °C vs. 1450 °C). It gains strength by permanently sequestering CO_2 and can undergo extensive recycling after completing its lifecycle.

The low hydration and carbonation degree of RM hindered the development of its properties. Motivated by the influence of amino acids on biomineralisation, this work aimed at investigating the impact of negatively charged L-glutamate acid (L-Glu) and L-aspartic (L-Asp), uncharged serine (L-Ser) and positively charged arginine (L-Arg) on the hydration and carbonation of RM. The observed different effects in hydration and carbonation among different amino acid-added samples can be attributed to their variations of the pH vs. isoelectric point gap, and a higher gap leads to a greater dissolution of MgO followed by higher hydration and carbonation degree, and then a higher strength.

This study also explores the mechanism of L-Asp of controlling the crystallisation of hydrated magnesium carbonates (HMCs) in carbonation cured MgO. It was observed that MgO carbonated without any amino acid formed Dypingite ($Mg_5(CO_3)_4(OH)_2{\cdot}5H_2O$) as the primary polymorph of HMCs. In contrast, amino acids as admixtures resulted in the formation of unstable Nesquehonite ($MgCO_3{\cdot}3H_2O$) during the carbonation of MgO. Additionally, the carbonated composites produced with amino acid were observed to have a higher carbonation degree and higher stability of the carbonated products, compared to the controlling batch without amino acid. TG/DTG, ICP-OES, XRD and SEM were utilised to provide a thorough understanding of the performance of MgO-L-Asp. The presence of amino acid resulted in the formation of denser carbonation products with a different morphology than those in the control mix, leading to significantly enhanced carbonation and strength.

Keywords: Reactive magnesia; Amino acids; Carbonates; CO_2 capture

Synergism of cement hydration and carbonation in the presence of CO_2 absorbed alkanolamine solutions

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ABSTRACT

In cement industry, reduction of CO_2 emissions becomes a major target due to the large amount of carbonate decomposition in clinker manufacturing. An innovative approach that employs CO_2 absorbed alkanolamine solutions directly as a cement additive is proposed in this research. Effects of CO_2 absorbed triethanolamine solutions (TEA-CO_2) on the mechanical property, phase composition and microstructure of cement pastes or mortars were investigated. Results showed that TEA-CO_2 addition increased the 1d, 3d, and 28d compressive strength by 47%, 19%, and 4%, respectively, which suggests a synergistic effect of triethanolamine and absorbed CO_2 on strength development of cement mortars. The enhancement is due to TEA-CO_2 accelerates hydration of aluminate and silicate phases in early age. TEA-CO_2 facilitated $CaCO_3$ formation to increase cement hydration degree and modify the pore structures. However, the hydration of silicate phases was delayed slightly by TEA-CO_2 at 28d. The above results provide theoretical support for further utilization of CO_2 in cementitious materials.

Keywords: CCUS; Cement; Carbonation; Hydration; Strength

Preparation of aragonite whisker-enriched materials via wet carbonation of magnesium slag combined with salt lake bischofite: the influence of aragonite whiskers on the properties of cement-based materials

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ABSTRACT

This study develops an innovative wet carbonation process utilizing magnesium slag, salt lake bischofite, and CO_2 to prepare carbonated materials mainly composed of aragonite. Subsequently, it was employed as a microfiber additive in cement, with the goal of efficiently capturing carbon dioxide and transforming aragonite whiskers into high-value products. Investigated the parameters influencing the formation of aragonite, including temperature, duration, and the concentration of the bischofite solution, while exploring the nucleation and growth mechanisms of aragonite. The findings reveal that under 80°C, the suspension of magnesium slag with 0.8% Bischofite solution swiftly produces needle-like aragonite whiskers with single crystal lengths ranging from 10-20μm and diameters of 0.5-2μm. With the increase in bischofite concentration, the aspect ratio of aragonite whiskers decreases. Additionally, highly polymerized amorphous silica gel was also detected. The mechanical properties of cementitious materials were significantly enhanced by incorporating CAMS into cement.

Keywords: Magnesium slag; Carbonation; Aragonite whisker; CO_2 sequestration; Mechanical property

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Construction of rigid-flexible interpenetrating network in carbonated magnesium slag composites by *in-situ* polymerization of acrylamide

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ABSTRACT

In-situ polymerization of acrylamide was utilized to tailor the mechanical properties of carbonated magnesium slag composites under a low water-binder ratio. The results revealed that appropriate acrylamide incorporation substantially enhanced the flexural and compressive strengths. This enhancement was attributed to the flexible polyacrylamide gels in-situ polymerized from acrylamide, which formed interpenetrating networks with the rigid magnesium slag carbonation products, thereby increasing compactness and toughness. Acrylamide incorporation did not alter the carbonation products but increased calcite formation. The polyacrylamide gels were uniformly dispersed in the carbonated matrix, reducing porosity and improving density. Moreover, acrylamide formed stable chemical bonds with cations released from magnesium slag. The temperature rise and CO_2 pressure during carbonation served as the dominating factors that initiated the in-situ polymerization. The established rigid-flexible networks synergistically amplified the flexural and fracture toughness. However, excessive acrylamide reduced the strengths due to phase segregation. The above results provide an efficient approach to establishing polymer-inorganic interpenetrating networks in magnesium slag carbonation systems, remarkably improving the mechanical performance.

Keywords: In-situ polymerization; Acrylamide; Magnesium slag; Carbonation; Mechanical properties

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Enhancing wet carbonation of recycled concrete aggregates by using reclaimed wastewater from concrete batching plant

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ABSTRACT

Wet carbonation technology is deemed an efficient and cost-effective approach for improving the mechanical properties of recycled concrete aggregates (RCAs) by enhancing the associated mortar/cement paste, where carbonation and hydration reactions occur concurrently. In this study, reclaimed wastewater (enriched in calcium) obtained from ready-mixed concrete plant replaced the conventional wet carbonating medium, tap water, to enhance the quality of RCAs and resulting recycled aggregate concrete (RAC). The density and water absorption of (i) natural aggregates (NAs), (ii) RCAs, and (iii) wastewater carbonated RCA (W-RCA) were compared. Additionally, the compressive strength, microstructure and other properties of resulting RAC, prepared using the three types of aggregates, were analyzed and compared. The results showed that the hydrolysis and subsequent hydration of RCAs in wastewater were impeded due to the high concentrations of Ca^{2+} in the liquid phase. Nevertheless, this circumstance enhanced the carbonation capacity of the solution. The Ca^{2+} from external sources was expected to induce more calcium carbonate precipitation in the wet carbonation system. The enhancement of RCAs quality after carbonation contributed to improved RAC performance. This study demonstrated a viable approach to integrate three waste resources (RCAs, wastewater, and waste CO_2) for the production of environmentally friendly concrete.

Keywords: Wet carbonation; RCAs; Recycled concrete; Hydration; Carbonation

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ORAL PRESENTATION
- Alkali-activated materials 2
(Session B3)

Performance of alkali activated fly ash cementitious materials at room and high temperatures

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ABSTRACT

Alkali activated fly ash（AAFA）cementitious material is an effective technical approach for resource utilization of large amount of fly ash storage in the northwest region of China，but the very slow polymerization rate of alkali activated fly ash (AAFA) cementitious material at room temperature cannot meet the setting and hardening requirements of *on-site* construction. In this paper, AAFA was prepared with ultra-fine fly ash and pre-activated crystal seeds at room temperature, and its working performance was optimized by superplasticizer. Its mechanical properties at room and high temperatures were studied and the thermal properties of AAFA after high temperature were improved by the Fe-based solid wastes. The Results showed that the AAFA paste prepared by partially replacing original fly ash with ultra-fine fly ash and adding appropriate amount of pre-activated crystal seeds exhibited the characteristics of rapid setting and high early strength at room temperature. Adding iron-based solid wastes, i.e., copper slag and iron tailing, could effectively improve the compressive properties of AAFA paste after high temperatures. The residual compressive strength increases by about 20 % at 800℃. Ihe mechanism of the effect of Febased solid wastes on the AAFA materials could be summarized as follows: after high temperature, the iron element in the Febased solid waste samples was more concentrated which may be caused by the melting of the original iron mineral phase into a new mineral phase, filling the crack gap. And the formation of the Fe-O-Si amorphous phase would improve the densification of samples, resulting in the improvement of compressive strength.

High temperature impact on sustainable fly-ash geopolymer mortar

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ABSTRACT

Geopolymer is an environment-friendly material and has the potential to reduce the carbon footprint of the construction industry due to the bulk use of fly ash instead of Portland cement. However, heat curing of fly ash-based binder systems limits its use in field applications. Therefore, attempts are being made to add suitable additives to achieve hardening of the binder system at room temperature. Several combinations of materials have been tried to produce geopolymer mortars and geopolymer concretes which could be cured at room temperature. In the present study, the geopolymer mortars have been prepared with fly ash, Ground Granulated Blast-furnace Slag (GGBS), natural sand and different concentrations of alkaline activators. The mortar cubes of 50 mm size were prepared using the above combinations and they were cured in air at room temperature for 28 days. The control mortar specimen was prepared using OPC and they were cured in water for 28 days. After 28 days, the specimens were exposed to high temperatures varying from 200°C to 1000°C for one hour. The compressive strength and the weight loss of the specimens were evaluated after exposure to high temperatures (200°C to 1000°C) and compared with OPC mortars. The results show that the resistance of geopolymer mortar (GPM) against exposure to high temperature is better than the conventional OPC-based mortar. The compressive strength gets reduced by 44% in the case of GPM and 67% in the case of OPC-based mortar. X-ray diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR) have been used to study the changes in the bonding behavior of C-A-S-H and N-A-S-H when exposed to high temperatures. These results indicated that the zeolite-like by-product of the N-A-S-H binder gel system in geopolymer mortar samples demonstrated superior stability at high temperatures as compared to OPC mortar.

Keywords: Compressive strength; Fly ash; Geopolymer; High temperature; Microstructure

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A Study on application of recycled concrete powder in alkali-activated cementitious system

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ABSTRACT

In this paper, the recycled concrete powder (RCP) was used as a supplementary cementitious material (SCM) in alkali activation system. The fluidity, rheological properties and mechanical properties were tested, while the effects of RCP on the hydration properties of alkali activated system were studied by XRD, SEM-EDS, thermogravimetric analysis and heat of hydration. The results show that the addition of RCP improves the fluidity of alkali-activated slag cementitious materials and changes the rheological index of paste. With the increase of RCP content, the compressive strength of alkali-activated slag cementitious materials increases first and then decreases. The addition of RCP has little effect on the types of alkali-activated hydration products, but increases the quantity of hydration products, and the inactive particles in RCP combine with hydration products to form a dense microstructure. The addition of RCP reduces the early and total hydration heat of alkali-activated slag cementitious material, delays the emergence of the second exothermic peak after the first peak.

Keywords: Recycled concrete powder; Alkali-activated cementitious material; Rheological properties; Mechanical properties; Hydration heat analysis

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Flowability and early-age mechanical properties of ultra-high performance geopolymer composites (UHPGC)

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ABSTRACT

Ultra-high performance concrete (UHPC), characterised by exceptional compressive strength, tensile ductility, and durability, has been applied in critical infrastructure, such as blast-resistant structures and long-span bridges. However, UHPC typically contains approximately three times as much cement as that in ordinary concrete, leading to significantly higher carbon emissions and energy consumption. Hence, ultra-high performance geopolymer composites (UHPGC) were developed to achieve lower carbon emissions while retaining good mechanical properties. Meanwhile, manufactured steel fibre was replaced with recycled tyre steel (RTS) fibre to enhance the sustainability of fibre reinforced composites.

In this study, flowability and early-age mechanical properties of UHPGC were characterised in terms of flowability, compressive strength, splitting tensile strength, and flexural strength. UHPGC specimens were prepared using fly ash and slag with a weight ratio of 20:80 as the binder, and a combination of NaOH and Na_2SiO_3 as the alkaline activator with the activator/binder ratio of 0.4. Silica fume was used with a 5% fixed weight ratio of the total precursors, and micro silica sand was added with a weight ratio of 20%. The effect of RTS fibre content (0, 1%, 1.5%, 2%) on flowability and early-age mechanical properties of UHPGC was estimated.

Results showed that the addition of RTS fibre lowered the flowability of fresh UHPGC mixtures due to the non-uniform fibre shape and geometry, potentially leading to fibre balling and agglomeration during mixing. The inclusion of RTS fibre resulted in the enhancement of compressive, because fibres delayed the initiation and propagation of cracks, and the total contact area between the matrix and fibres was improved. The flexural strength of UHPGC was significantly improved by incorporating RTS fibres by enhancing matrix-fibre contact area and load-bearing capacity.

Keywords: Ultra-high performance geopolymer composites (UHPGC); Alkali-activated materials; Fibre reinforced composites; Recycled tyre steel fibre; Mechanical properties

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Study on the effect of pre-excitation on the high-temperature properties of alkali-activated fly ash materials

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ABSTRACT

To promote the high-temperature application of alkali-activated fly ash (AAFA), it is vital to thoroughly understand the performance of AAFA at elevated temperatures. In this paper, AAFA was prepared by pre-excitation process, and chemical composition of AAFA slurry were characterized by X-ray diffraction and Fourier transform infrared spectroscopy, and the pore structure of AAFA slurry was systematically studied by mercury intrusion. The results show that the pre-excitation process makes the pore distribution of the AAFA test block more uniform, reduces the damage to the matrix when water escapes, and increases the residual strength of the AAFA test block after exposure to 1000°C by 75.5%. The pre-excitation enlarged the crystal lattice of quartz and mullite, and after exposure to high temperature, quartz and mullite were transformed into amorphous gels, which repaired the microcracks caused by water escaping at high temperatures.

Keywords: Alkali activated fly ash (AAFA); Pre-activated crystal seeds; Preparation method; Properties at high temperature

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Effect of thermal treatment conditions (temperature level and nature of fluxing agents) on the reactivity of synthetic precursors

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ABSTRACT

The application of alkaline activation technology makes it possible to produce cements free of clinker (alkaline cements). In the manufacture of these cements, aluminosilicates of amorphous or vitreous structures, such as calcined clays or industrial by-products (fly ash, blast furnace slag, mining waste, etc.) are used as precursors. The use of these precursors has two disadvantages: the lack of homogeneity and the lack of availability in the necessary quantities.

In order to solve these problems, the objective of this work is focused on the manufacture of precursors with a composition similar to a type C fly ash. More specifically, the influence of the incorporation of several fluxing agents (≈ 5% by weight), as well as the effect of the calcination temperature (1000 and 1250ºC) on the reactivity of the precursors, have been analyzed. The manufactured precursors were characterized by XRD and 29Si and 27Al MAS NMR. The reactivity of the different precursors was tested in alkaline medium (NaOH 8M). For that, 1*1*1 cm3 pastes specimens were cast, and the strengths were evaluated after 20h of curing (85oC, 99%RH). All alkaline cements, especially those prepared at 1250oC, set and harden developing very good strengths (between 60 and 110 MPa), indicating its high potential to be used as a precursor for the preparation of these cements.

Keywords: Synthetic precursor, Fluxing, Sustainable cements, Alkaline cements

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ORAL PRESENTATION
- Emerging technology 3
(Session C3)

Characterization on ingress of CO_2 and Cl^- in hardened cement paste with XCT

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ABSTRACT

X-ray computed tomography (XCT) can non-destructively detect microstructure of cement-based material. However, its raw results involve errors induced by the equipment and external factors. Once studying changes taken place in a sample, such as durability related studies, which need testing on a same sample at intervals, these errors will result in misleading conclusions. After testing and analysing ten series of XCT results for samples experiencing various types of exposures, authors established a rational data-processing method to minimise the influence of these errors on test results. In this paper, details of the processing method are clearly illustrated, as well as its application and findings in one dimensional ingress of CO_2 and Cl^-. Obtained results prove that diffusion of substances in the hardened cement paste can be prop-erly revealed with the data processing method introduced; the immersion of samples in NaCl solution led to a gradual decrease in density and a further hydration of cement particles; the change of microstructure in the 0.35 w/c was slower than that in the 0.5 w/c sample at a certain NaCl solution, and the influence depth had an approximate linear relationship with square root of immersion duration; microstructure changes in hardened cement paste under carbonation is a coexisting simultaneous densification and cracking process; under carbonation, the changes exhibited a general alternate pattern of densification–cracking–redensification, leading to connection of micropores into macro ones in hardened cement paste.

Keywords: XCT; Data processing; Carbonation; Chloride ingress

Nacre like ultra-tough calcium silicate hydrate (C-S-H) composite toward elastic cementitious materials

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ABSTRACT

The low toughness of cement and concrete materials has been a long-standing issue for decades and has become increasingly urgent to address in modern society due to the growing demand for the development of high-performance and sustainable constructions. Manipulating calcium silicate hydrate (C-S-H), the main hydration product of Portland cement, which determines the mechanical properties of cementitious materials, is an attractive approach to improving their toughness following a bottom-up approach. Inspired by nacre, an ultra-tough C-S-H-based composite with a highly ordered structure has been fabricated by a designed ternary building block, in which exfoliated montmorillonite (MMT) provided a template for the nucleation and growth of C-S-H and polyvinyl alcohol (PVA) acted as a “mortar” binding all the building blocks together. With the hierarchical toughening strategy explored here, the obtained C-S-H composite achieves a remarkable tensile toughness of 16.2 ± 2.6 MJ/m^3, which surprisingly outperforms the fiber-reinforced ultra-high performance cementitious materials (FRUHPC) by a factor of 20~60 and even higher than that of natural nacre and other nacre-like composites. Our findings not only provide valuable insights into enhancing the toughness of cementitious materials but also open possibilities for broadening potential applications of C-S-H.

Keywords: Nacre inspired; calcium silicate hydrate (C-S-H); montmorillonite; toughness; cement

Preparation, performance and typical application of construction and demolition waste residue soil recycled foamed concrete

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ABSTRACT

Construction and demolition waste residue soil (CDWRS) recycled foamed concrete was prepared by introducing original CDWRS into low-carbon binders, and pore structure, hardened performance and typical application were also investigated. The results indicated that this low-carbon foamed concrete containing 988~1126kg/m^3 of CDWRS could be obtained by adding water glass and gypsum into low-carbon binders, and its dry density, thermal conductivity and 28-day compressive strength were 626 kg/m^3 ~ 948 kg/m^3, 0.11 W/(m·K) ~ 0.14 W/(m·K) and 0.55 MPa ~ 7.76 MPa, respectively. Utilization of this foamed concrete in sandwich structure could fabricate energy-saving wallboard with a heat transfer coefficient of 0.75 W/(m^2·K) ~ 1.01 W/(m^2·K) and compressive strength of 16.5 MPa~ 24.6 MPa.

Keywords: Construction and demolition waste residue soil; Foamed concrete; Pore structure; Hardened performance; Applicaiton

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Fabrication of phosphogypsum-based cold-bonded self-healing artificial lightweight aggregate and its self-healing performance

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ABSTRACT

Micro-cracks are an inherent feature of cementitious materials leading to the deterioration without proper control or instant maintenance, which could be partially solved by employing self-healing technology. Meanwhile, as one of the bulk solid wastes, novel recycling of phosphogypsum in manufacturing phosphogypsum-based self-healing fine aggregates (PSAs) through cold-bonded technology could promote its utilisation as well as improve the self-healing performance of concrete. This study introduced the PSAs with urease-producing bacteria as a strategy for self-healing cracks. In the study, the artificial aggregates were firstly prepared via cold-bonding process and then the prepared aggregates were sucked in bacterial solution to load the microbial repairing agent. Then the bacterial loaded PSA was wrapped by outer layer of magnesium phosphate cement and carbonation. After characterising its properties, the PSA was used to replace the natural fine aggregate at 50% and 100% levels. The self-healing ability was evaluated by compressive strength, splitting strength, compressive strength recovery percentage and microscopic detection of crack healing. The results showed that the 28d compressive strength of mortar prepared PSA was generally in the range between 22 MPa - 33 MPa, and the leaching performance was excellent as well. For self-healing performance, the maximum crack width was 0.76mm, which could be completely healed after 28 d of dry-wet cycle curing. Moreover, the compressive strength recovery rate was between 62% and 88%. Scanning electron microscopy and X-ray diffraction confirmed that the crack healing product was mainly calcite-type $CaCO_3$.

Keywords: Self-healing; Phosphogypsum; Cold-bonded; Artificial Aggregate; Cracking

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A scale for decarbonising concrete

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ABSTRACT

The objective of this work is to review emerging classification scales on decarbonising concrete that attempt to support designers, material suppliers and policy makers to achieve Net Zero targets in the construction sector. The review highlights gaps and areas for improvement. Existing classification scales were found in both academic and grey literature. They were shared and reviewed at a workshop with concrete experts. Workshop findings were written up and experts were asked to correct and verify the conclusions. The key findings of the study are as follows: (1) decarbonisation scales consider the carbon intensity of concrete ($kgCO_2e/m^3$) used in a construction project and not the consequences of reducing the volume of concrete through alternative structural designs for example; (2) by definition the scale is concerned only with carbon and not any other undesirable effects, such as other greenhouse gases emitted per volume of concrete; (3) the carbon intensity is underrepresented as it reflects only the carbon embodied in the material during construction, not extraction, and not operational use or end of life; (4) some classifications focus on just concrete strength which leads to a different carbon intensity, ignoring production methods (which can change over time to be more efficient), transport to site (which can improve to use cleaner fuels), etc; (5) limitations on the availability of cement alternatives, such as pulverised fly ash, are overlooked; and (6) new methods and mixes are continually being developed, requiring continuous revision of the scale. An alternative decarbonisation scale is proposed to address these short-comings and incorporate learning from decarbonisation scales of other construction materials: steel, asphalt and diesel. The new scale builds on the benefits of a usable, concrete decarbonisation scale particularly the signalling to materials' producers and suppliers that lower-carbon alternatives are acceptable and desirable to meet Net Zero targets.

Keywords: Decarbonisation; Classification scales; Concrete; Embodied carbon; Cement

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Heavy metal immobilization through basic magnesium sulfate cement: Efficiency and mechanism

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ABSTRACT

Basic magnesium sulfate cement (BMSC) possesses advantages of high early strength, good toughness, and rapid setting time, making it applicable in civil engineering. However, BMSC systems are characterized by low alkalinity, which presents potential advantages in the treatment of heavy metal waste. This study investigates the impact of typical heavy metal cations (Zn, Cu, and Pb) on the compressive strength, setting time, and leaching toxicity of BMSC. Additionally, the hydration heat evolution process, hydration product phases, and the evolution of microstructure and pore structure of BMSC under the influence of heavy metal cations were characterized. Finally, the immobilization mechanisms of BMSC for Zn, Cu, and Pb are proposed. The results confirm that Zn, Cu, and Pb can decrease the compressive strength of BMSC and prolong its setting time, albeit to a limited extent. Leaching toxicity shows that the leaching rates of Zn, Cu, and Pb from the BMSC matrix are far below the standard requirements. Moreover, Zn, Cu, and Pb extend the induction period of BMSC, reduce the heat evolution rate, and the total heat evolved during hydration. This indicates that BMSC exhibits excellent immobilization efficiency for Zn, Cu, and Pb. Combining the results of phase composition and microstructural evolution, it is found that, in addition to the physical encapsulation by the BMSC matrix, the immobilization mechanisms of BMSC for Zn, Cu, and Pb include the primary hydration product (5-1-7 crystals) undergoing lattice substitution with heavy metal cations, thereby imparting excellent immobilization efficiency of BMSC for heavy metal cations.

Keywords: Basic magnesium sulfate cement; Leaching toxicity; Immobilization mechanism; Heavy metal

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ORAL PRESENTATION
- Carbonation & Decarbonisation 2
(Session A4)

Coupling effect of CO_2 mineralization of steel slag and carbonation curing of cement-based materials

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ABSTRACT

It is well known that carbonation curing can effectively sequester CO_2 and improve strength and durability of cement-based materials. Due to the low permeability, the carbonation reaction normally occurs in the outer layer of cement concrete specimens and the CO_2 capture potential could not be fully exploited. The CO_2 mineralization of industrial wastes has been also recognized as one of the most promising carbon capture and storage technologies and the carbonated material can be used as mineral admixture for cement concrete. In this study, steel slag was pre-carbonated under different CO_2 concentrations and durations and then the carbonated steel slag was used as mineral material to replace Portland cement. The steel slag added mortars were exposed to carbonation curing condition and the coupling effect of these two CO_2 capture processes were discussed based on both mechanical properties and microstructures. It was found that the CO_2 mineralization decreased the early-stage activity of steel slag due to the formation of a dense calcite barrier layer on mineralized steel slag particles. And the later-stage activity can be improved, being attributable to the accelerated hydration effect of silica-rich phase and nucleation effect of calcite. The synergistic effect of CO_2 mineralization and carbonation curing can efficiently improve the CO_2 sequestration and compensate the early age strength reduction with the addition of steel slag. Therefore, this study provides a new method for preparing low-carbon cement-based materials.

Keywords: CCUS; Steel slag; Carbonation; Mineral admixtures

Carbonation process for sustainable low-carbon concrete

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ABSTRACT

Industrial and natural carbon dioxide (CO_2) emissions are among the primary greenhouse gases currently exacerbating global warming. The concrete industry is a significant source of global CO_2 pollution responsible for approximately 7% of emissions per annum. A prospective solution that exhibits immense potential with regard to sustainability is that of geopolymer technology which can reduce the amount of CO_2 emitted and thus mitigate the environmental impact of the construction sector.

In this research, steel slag waste materials were used to manufacture geopolymer concrete. Two sets of samples were made per batch. The samples were then cured in a CO_2 incubator for different periods of time, one under CO_2 conditions and the other without CO_2. The results indicate that, compared with non-CO_2 cured samples, CO_2 sequestration increased markedly in samples cured under CO_2 conditions. Over 28 days without CO_2, CO_2 sequestration increased from 2.37 to 2.77 kg of CO_2 per ton of geopolymer concrete whereas exposure to CO_2 over the same period yielded a significant increase in carbonation levels from 6.01 to 20.97 kg of CO_2 per ton of the geopolymer concrete. However, unlike non-CO_2 cured samples, efflorescence caused by CO_2 exposure during curing lowered the bending and compressive strengths of geopolymer concrete. Nevertheless, the results indicate the feasibility of scaling up the process for industrial applications and to promote the widespread usage of low-carbon cement and concrete technology.

Keywords: Geopolymer concrete; Steel slag; Carbon sequestration; CO_2 incubator; Compressive strength

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Ultra low emission CO_2-activated self-pulverising Portland cement and concrete

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ABSTRACT

The innovative scheme described here for the linked production of cement and concrete with an ultra-low carbon footprint follows a three-stage process. Firstly, a Portland-like cement composition, but containing less limestone, is calcined at reduced temperature and cooled under controlled conditions so that it self-pulverises spontaneously to a powder of normal fineness, thus avoiding the need for grinding. Secondly, CO_2-rich gas is extracted straight from the cement kiln flue and used in a third stage to activate this weakly hydraulic binder to make precast concrete products. Direct and indirect reductions in CO_2 emissions of 25% compared with Portland cement concrete are anticipated in this process, together with considerable energy and cost savings. In addition to its use in precast concrete, several potential on-site applications are foreseen for this cement where low-energy concrete or controlled setting are required. Further secondary sustainability gains and other commercial advantages are expected from new applications such as 'set-on-demand' concrete (triggered by injection of CO_2) and management of hazardous waste. By combining this novel binder with secondary aggregates made by carbonating siliceous wastes such as air pollution control residues, a truly net zero emissions concrete could become a reality.

Keywords: Portland cement; Low carbon emissions; Self-pulverising cement; Accelerated carbonation; Precast concrete

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Enhanced carbonation of steel slag blocks using various chemical additives

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ABSTRACT

Utilizing industrial by-products for environmental remediation is a sustainable approach to waste management. In this study, steel slag, a by-product of the steelmaking process, presents a significant opportunity for CO_2 sequestration through carbonation curing. Traditional carbonation methods for steel slag typically require the use of pure CO_2 under elevated pressures, which is not always practical due to the specific transport and kinetic characteristics of CO_2. This study explores the carbonation of steel slag blocks under ambient conditions, using a 30% CO_2 concentration, which is more feasible for large-scale applications. To accelerate the carbonation, the effectiveness of various chemical additives was investigated, including chelating agents (EDTA and its sodium salt, MA-AA, IDS-4Na), inorganic alkali activators (water glass, Na_2CO_3), and sulfates (gypsum, Na_2SO_4), in enhancing the compressive strength and carbonation efficiency of the steel slag blocks. The results indicated that all tested chemicals facilitated an increase in CO_2 absorption. However, despite their effectiveness in CO_2 uptake, the addition of Na_2SO_4 and Na_2CO_3 did not correspond to the highest compressive strength. This phenomenon was attributed to the formation of dense carbonate layers on the surface of the blocks, which hindered the complete carbonation of the inner material. Microscopic analysis identified calcite as the dominant product of carbonation. In contrast to chelating agents, which expedite the carbonation process directly by promoting the leaching of calcium and magnesium from the slag. Inorganic alkali activators and sulfates were found to accelerate the carbonation by the formation of C-(A)-S-H and ettringite, respectively, which are more amenable to carbonation than the original mineral phases in steel slag. This research offers valuable insights into the preparation of carbonated steel slag products using lower CO_2 concentrations at ambient pressure, contributing to the development of more sustainable construction materials and CO_2 sequestration techniques.

Keywords: Accelerated carbonation; Steel slag; Chemical additives; Compressive strength; Chelating agents

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ORAL PRESENTATION
- Chemical admixture
(Session B4)

Low carbon concrete admixtures - A new class of products for concrete net zero 2050 scenario

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ABSTRACT

Among the main actions to a net concrete zero future, saving in cement and binders by replacement of clinker with supplementary cementitious materials (SCMs) is expected to be a major task. Nevertheless, it is well known that SCMs react slower compared to clinker and can negatively affect the strength development, both at early and long curing times. Moreover, clinker itself never hydrates completely and residual unreacted fractions always remain in concrete. Under such premises, the expected reduction of the clinker-to-cement ratio from the actual value of 0.71 to the target value of 0.57 by 2050 might be hardly achievable. Low Carbon Concrete Admixtures (LCCAs) is a new class of admixtures that comes alongside the existing water reducers, retarders and accelerators and it is destined to take on a prominent role as an essential integration for the sustainability of concrete. LCCAs increase the degree of hydration (DoH) of blended cements and compensate the decline of both early and final strength of blended cements compared to Portland cements. By increasing both DoH and the final strength, LCCAs promote a more rationale use of cement. At the same dosage of cement, LCCAs permit to cast more resistant and durable concrete. Alternatively, they allow to achieve the same compressive strength with reduced dosage of cement. Moreover, by using LCCAs it is possible to increase the fraction of SCMs in blended cements and in concrete without detrimental effects on compressive strength. In the present work, an introduction to the new class of LCCAs is presented with examples how they can be effectively used to reduce the carbon foot-printing of concrete in the view of the Net Zero 2050 Scenario.

Keywords: Blended cements, Carbon neutrality, Degree of hydration, Low carbon concrete admixtures, Supplementary cementitious materials

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The adsorption behavior of water-reducing agents in natural hydraulic lime: Impacts on rheological properties and early hydration

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ABSTRACT

Grouting repair is a widely employed method for reinforcing and restoring brick and stone cultural relics. The favorable rheological properties of natural hydraulic lime (NHL) are crucial for its successful application. This paper investigates the adsorption behavior of water-reducing agents, including naphthalene-based (NSF), melamine-based (PMS), and polycarboxylate superplasticizers (PCE), in NHL pastes. Subsequently, it also investigates their impact on the rheological behavior and early hydration of fresh pastes. The types, content, and microscopic morphology of hydration products were characterized using XRD, TG-DSC, and SEM. Results indicate that NSF and PMS primarily disperse lime particles through electrostatic repulsion, while PCE is predominantly controlled by steric hindrance effects. NSF, PMS, and PCE effectively enhance the rheological properties of fresh lime slurry, with PCE demonstrating the most substantial improvement. In the NHL system, $Ca(OH)_2$ competes with C_2S for adsorption, and $Ca(OH)_2$ absorbs a significant amount of negatively charged water-reducing agent molecules, markedly reducing the dispersion efficiency of the water-reducing agent. For the NHL2 system, the saturated content of PCE is 0.8wt%; for the NHL5 system, it is 0.4wt%. Among all water-reducing agents, PCE exhibits the best compatibility with NHL slurry. PCE enables high fluidity of NHL-based grouting materials at low water-cement ratios, significantly reducing shrinkage during the hardening process and ensuring stable strength development. The combination of PCE and NHL emerges as a highly promising grouting and restoration material for brick and stone cultural relics.

Keywords: NSF; PMS; PCE; Natural hydraulic lime; Grouting repair

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The pore structure of cementitious material modified by hydrophobic agent

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ABSTRACT

One of the most effective methods to improve durability of cementitious materials is to resist the intrusion of water with aggressive ions by mixing with hydrophobic agent. In this study, the mechanism of carboxylic acid ammonium salt hydrophobic agent addition on hydrophobicity of cementitious materials is analyzed. The impact of hydrophobic agent on water adsorption, moisture diffusion and hydration products is investigated by experimental method. It is shown that carboxylic acid ammonium salt hydrophobic agent performs the excellent water repellence. The results of water vapor sorption isotherm show that the addition of carboxylic acid ammonium salt increases the pore volume. The simplified analytical hydrodynamic model of cone type pore and Young's relationship is proposed to analyze the relation between characteristic parameters of pore and the permeability of cementitious materials. It can be concluded that the hydrophobicity results from the change of pore structure and the hydrophobic surface of cone region. These results provide the guidance to design the durability and develop the new hydrophobic agent used in cementitious material.

Keywords: Hydrophobicity; Permeability; Pore structure; Hydrodynamic effects

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Unlocking the strength potential of ordinary Portland cement: a novel hydration control additive for enhanced performance and reduced environmental impact

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ABSTRACT

Ordinary Portland cement (OPC) serves as a fundamental constituent in the construction industry, which is used in a wide range of construction materials. Despite its widespread utilization, the complete exploitation of OPC's strength-generating capacity remains unrealized, primarily due to limitations associated with the conversion of aluminates to ettringite, as governed by conventional hydration kinetics. We present a hydration control additive that selectively modifies the hydration kinetics of OPC, thereby facilitating an enhanced dissolution of aluminates, including calcium aluminoferrite and tricalcium aluminate. This modification promotes the formation of ettringite at a desired time, contingent upon the presence of an appropriate quantity of sulfate. The augmentation of ettringite content, in turn, improves the packing characteristics of the cured cement, resulting in a notable ~50% increase in specific strength and enabling a reduction in cement consumption. Moreover, the incorporation of this hydration control additive not only enhances OPC's strength development efficiency but also enables a reduction in the carbon footprint by approximately 40%. Furthermore, the introduction of the additive confers an added advantage in terms of significant improvement of the overall sulfate resistance of the cementitious material, even in the presence of elevated sulfate levels. This is attributed to the early hydration of aluminate phases facilitated by the additive. In summary, the development of this innovative hydration control additive offers a promising avenue for fully harnessing the latent potential of OPC.

Keywords: Hydration control additive; Aluminates; Ettringite formation; Strength development efficiency; Sustainability

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ORAL PRESENTATION
- Calcined clay
(Session C4)

Improving the early strength of PLC and LC^3 using BCSA as a mineral admixture

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ABSTRACT

The early strength of PLC and LC^3 is improved by the addition of belitic calcium sulfoaluminate (BCSA) cement. Portland limestone cement (PLC) concrete and limestone calcined clay concrete (LC^3) are promising options in the development of low- carbon cements, but many field reports indicate shortcomings in their early strength performance. It is also desirable to increase the market attractiveness of these low-carbon binders by improving their early strength.

This study explores accelerating these binders with BCSA as a low-carbon mineral admixture that does, in its own right, provide early strength. Blends of BCSA, PLC, and calcined clay (CC) in different ratios were tested against pure BCSA, PLC, and LC^3. The setting time, compressive strength, and drying shrinkage were tested. Additionally, the Global Warming Potential (GWP) of the blends was calculated, and the carbon intensity was estimated as the total weight of carbon dioxide (CO_2) equivalent per unit of compressive strength at several times. Blends of PLC and LC^3 with BCSA could reach a compressive strength of 10 MPa at 1.5 hours. While blends showed a lower rate of strength development compared to pure BCSA, they achieved similar strengths after 28 days. While it is known that the shrinkage of BCSA is 20 to 30 percent of the shrinkage of PLC and LC^3, it was interesting to find that the drying shrinkage of specific blends can match the shrinkage performance of BCSA. It is concluded that the carbon footprint per unit performance, or GWP, of these BCSA blended cements, is lower than conventional Portland cement and can play a role as an intermediary step toward net-zero while other alternatives are developed.

Keywords: Belitic Calcium Sulfoaluminate, Low-carbon cement and concrete

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Mechanically and thermally activated clays: A novel perspective on SCM applications

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ABSTRACT

Clay minerals are gaining attention as Supplementary Cementitious Materials (SCMs) due to their aluminosilicate composition and great abundancy globally. However, their use has been rather constrained due to their mineralogical complexity as well as practical issues with low early strength when used in composite cement. The clays' reactivity can be improved through different treatments that transform their crystalline structure into an amorphous or disordered state. This study compares thermal and mechanical activation on six clays, investigating their reactivity as SCMs in composite cement. The reactivity of activated clays is evaluated via compressive strength tests up to 28 days on mortars comprising binders with 20% clay and 80% Ordinary Portland Cement (OPC) by weight. The results show that mechanical activation can improve the reactivity of clays with high contents of 2:1 minerals (e.g. smectite) or with high contents of impurities (e.g. quartz) compared to thermal activation. For clays with high contents of 1:1 minerals (e.g. kaolinite), thermal activation shows to be a more effective treatment at a calcination temperature of 750°C when compared to mechanical activation. Altogether, the study findings provide new insights on tailoring activation routes according to the clay mineralogy to enhance their performance when used as SCM in composite cement.

Keywords: Clays; Mechanical activation; SCMs; Thermal activation

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Unlocking the potential of UK clays for the production of low-carbon cements

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ABSTRACT

This study evaluated the potential of different UK clays to be activated with the purpose of using them as supplementary cementitious materials (SCMs). A comprehensive field survey was carried out by the British Geological Survey, collecting more than 41 different clay samples from different locations. The clay samples were subjected to laboratory-based characterization, analysing their chemical and mineralogical composition through X-ray fluorescence spectroscopy (XRFS), X-ray diffraction (XRD) and thermogravimetric analysis (TGA). The majority of clays contained <40 wt.% kaolinite; the total clay content ranged widely from 10 – 82 wt.%, and carbonate minerals were frequently present, up to 20 wt.%. Clays were classified into four groups based on their mineralogical composition; from the two groups with mineralogical attributes deemed most suitable for calcination, 11 selected clays were then calcined at 800°C and their chemical reactivity was determined using the calorimetry method of the R^3 test. Results revealed that after thermal activation, UK clays yielded R^3 values ranging from 200 to 500 J/g SCM, classifying them as SCMs with moderate reactivity. Although clays with higher kaolinite content typically exhibited superior reactivity, the results indicated that additional factors, such as total clay content, need to be considered for predicting reactivity, particularly for mixed clays.

Keywords: UK clays, Kaolinite, Chemical reactivity, SCMs, Calcination, R^3 test

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Microstructure and mechanical performance of GFRP bars embedded in LC^3 concrete

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ABSTRACT

The combination of glass fiber reinforced polymer (GFRP) and limestone calcinated clay cement (LC^3) concrete is expected to exhibit significant merits on the excellent resistance of GFRP against chloride attack and the low-alkaline environment provided by LC^3 concrete. This combination aims to mitigate the GFRP degradation and thereby extend the service life of marine structures. However, the underlying mechanism of GFRP-LC^3 remains unclear. To address this issue, this study focuses on comprehensively investigating the time-dependent degradation of GFRP in LC^3 through conditioning GFRP-LC^3 specimens in water baths at temperatures of 23, 40, and 60°C for durations of 21, 45, and 90 days. Both macroscopic tensile testing and microstructural analysis are employed to gain deeper insights. The experimental findings indicate that, when compared to normal concrete (NC), LC^3 exhibits reduced aggressiveness towards the embedded GFRP bars due to its lower alkaline content. Nonetheless, GFRP bars still experience fiber corrosion, matrix cracking, and fiber-matrix debonding as a result of alkaline attack from LC^3. It is observed that GFRP-LC^3 displays a higher tensile strength retention than GFRP-NC under identical environmental conditions. These outcomes contribute to a better understanding of GFRP behavior in the context of LC^3, enabling the advanced design and construction of structures with enhanced performance and longevity.

Keywords: GFRP; LC^3; Alkaline attack; Tensile strength retention; Microstructural analysis

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ORAL PRESENTATION
- Waste utilisation 1
(Session A5)

Insight into the mechanism underlying steel corrosion resistance of recycled aggregate concrete (RAC) by incorporating waste glass powder

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ABSTRACT

Conventional supplementary cementitious materials would decrease the alkalinity of pore solution, which is not beneficial for the stabilization of passive film on the surface of steel bars in the marine environment. By leverage of the alkali-rich and pozzolanic characteristics, this study first valorized waste glass powder (GP) to enhance the corrosion resistance of recycled aggregate concrete (RAC). The results showed that partially replacing cement with GP could improve the steel corrosion resistance of RAC to a level better than conventional concrete prepared with natural aggregates. Moreover, the presence of 20% GP significantly enhanced the chloride penetration resistance at a later age without sacrificing the compressive strength. The enhanced corrosion resistance of GP-RAC was attributed to two main reasons: i) the refined pore structure by the formation of secondary C-(N)-S-H gels with a lower Ca/Si ratio; ii) the increased alkalinity of pore solution due to the depolymerization of GP and the released Na^+ from GP. As a result, the use of GP in low-carbon cement was able to compensate for the inferior durability of RAC. The proposed corrosion-resistant concrete with low ecological and economic costs has a promising application potential to promote the wider use of GP and RAC in the construction sector.

Keywords: Recycled aggregate concrete; Glass powder; Compressive strength; Chloride penetration; Steel corrosion

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Materials design and strength development of a novel cold recycled mixture with asphalt emulsion and geopolymer

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ABSTRACT

The objective of this paper is to develop a novel cold recycled asphalt mixture stabilized with asphalt emulsion and geopolymer (CRM-GE), which has far more lower carbon dioxide emission and energy consumption compared with conventional hot mix asphalt (HMA). Firstly, the effects of mixing sequence, geopolymer content, asphalt emulsion content and curing conditions on the strength of the mixture and its time-dependent law are studied. Then, the microstructure and composition of the mixture are analysed by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). The results show that the optimum amount of asphalt emulsion is different under different geopolymer content. When the content of geopolymer is 4 %, the optimum amount of asphalt emulsion is 4 %. When the content of geopolymer is 6 %, the optimum amount of asphalt emulsion is 3%. The indirect tensile strength of the mixture specimen increases with the increase of the curing time, and the increase of the curing temperature can effectively improve the early strength of the mixture. The microstructure analysis indicates geopolymer reaction and asphalt emulsion demulsification in CRM-GE with 7-day curing are relatively limited, while asphalt membrane and the geopolymer reaction products is intertwined to achieve a denser microstructure in CRM-GE with 28-day curing. In addition, the elements analysis indicates that Ca, Si, C, Na, Al and O are uniformly distributed in geopolymer-asphalt mortar, which further verify the result of materials design and micromorphology analysis.

Keywords: Cold recycled mixture; Asphalt emulsion; Geopolymer; Mechanical properties; Microstructure

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Properties of the cementitious mortars incorporated wind turbine blade waste

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ABSTRACT

The blades of wind turbines are typically made of glass fiber-reinforced polymers, posing challenges for recycling. This study investigates the incorporation of shredded wind turbine blade (WTB) wastes into cementitious mortars and evaluates their fiber reinforcement potential. The WTB wastes were initially sieved and separated into three size fractions: flakes (1.4-40 mm), fiber fluffs (1.4-0.6mm) and WTB powder (below 0.6mm). The fiber fluff consists mainly of a mix of fiber and powder. Shredded WTB wastes were used in 2% of the total mixture volume in mortars. The prepared samples underwent flow-table, compression, and three-point bending tests. All the samples containing shredded WTB wastes led to decrease in flowability, particularly with larger waste sizes. WTB use resulted with decrease in 28 days compressive strength and a relative increase in bending strength, at the same age. Samples containing fiber fluffs exhibited deflection softening behavior while the samples with flakes demonstrated deflection hardening behavior with a 12% increase in bending strength.

Keywords: Wind turbine blades (WTB); Mortar; Glass fiber reinforced polymer (GFRP); Flowability; Mechanical properties

The micro and macro properties of low-carbon ultra-high-performance concrete with waste concrete powder

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ABSTRACT

Due to the incomplete hydration of a large amount of cement only serving as a physical filler in Ultra-high performance (UHPC), it is considered to replace cement with recycled concrete powder (RCP) which was produced from the resource utilization of construction and demolition waste, in order to produce low-carbon UHPC with RCP and cut down the high carbon emissions and high costs brought about by cement utilization. This work investigated the role of RCP in the UHPC system, and analysed its hydration reaction through tests, including X-ray diffraction (XRD) and isothermal calorimetry. The mechanism of mechanical strength was also analysed. The results showed that under the standard curing condition, the inclusiveness of RCP reduced the adiabatic heating of the RCP-UHPC system. With the increase of substitution rate of RCP, the content of un-hydrated cement was decreased, and the hydration reaction of cement was promoted and become more complete with the increased reaction degree. The mechanical strength showed a trend of first increasing and then decreasing, following the RCP substitution. Optimizing substitution rate of RCP can prepare UHPC with good mechanical strength and lower carbon emissions.

Keywords: Ultra-high-performance concrete; Recycled concrete powder; Hydration mechanism; Chemical composition; Mechanical strength c

Impact of cement with a high recycle rate of calcined clay on the behavior of self-compacting mortars

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ABSTRACT

Cement manufacturing is responsible for approximately 7% of global industrial emissions, while the construction industry stands out as one of the largest consumers of natural resources and energy, generating significant waste. The production of cement and aggregates not only depletes natural resources but also contributes to greenhouse gas emissions. Additionally, concrete structures are susceptible to degradation due to chemical and physical environmental factors, necessitating rehabilitation, especially after natural disasters such as earthquakes. This leads to increased cement consumption and waste production. This study aims to develop self-compacting mortars by incorporating varying proportions of fine brick waste from a local manufacturing unit, substituting different rates of cement (0%, 20%, 30%, and 40%). The research involves analyzing rheological behavior in the fresh state and mechanical performance in the hardened state. Various mortars were subjected to rheometer tests, V-Funnel, and the mini-cone slump test analysis to study their rheology. In the hardened state, compressive strength tests were conducted. The results indicate that the inclusion of fine brick waste leads to a decrease in workability and an increase in viscosity in self- compacting mortars. Despite the occurrence of pozzolanic reactions, there was no observed improvement in compressive strength but the results remain comparable to the control mortars.

Keywords: Cement substitution; Brick waste; Self-compacting mortar; Rheology; Compressive strength

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Self-foaming lightweight aggregate from waste glass and incinerated sewage sludge residues

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ABSTRACT

Waste glass powder (WGP) and incinerated sewage sludge residues (ISSR) were used as raw materials to produce self-foaming lightweight aggregate (LWA). WGP provided the glassy matrix and reduced the softening temperature, while ISSR acted as a self-foaming agent. The study aimed to investigate the influence of WGP: ISSR ratio (50:50 to 75:25) and foaming temperature (750 °C to 950 °C) on the amount of the pore structure and mechanical properties. Increasing WGP content resulted in a reduction in porosity but an increase in the proportion of closed pores, improving the mechanical strength. Higher foaming temperatures led to increased volume expansion, higher total porosity, and lower strength. It was found that LWA with 75: 25 WGP: ISSR ration formed at a foaming temperature between 800 and 900 °C had optimal strength and uniform pore distribution.

Keywords: Incinerated sewage sludge; Waste glass; Lightweight aggregate; Self-foaming

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ORAL PRESENTATION
- Durability 1 (Session B5)

Durability of low carbon binders with GGBS and/or high limestone filler content (50%)

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ABSTRACT

To reduce the environmental impact of cement production and to save energy, one solution is to massively replace clinker by supplementary cementitious materials (SCM) to design binary or ternary binders. However, these low clinker binders can have various phase assemblages and pore structures which may impact the durability of concretes. In particular, as corrosion is the main cause of damage in reinforced concretes, whether due to chloride ingress or carbonation of concrete, specific attention should be given to this aspect of durability. In addition, damage due to sulphate is to be studied.

Three low carbon binders with up to 40% clinker, CEM III/A (40% OPC), CEM III/B (32% OPC), and one very low clinker ternary binder (CLS) - OPC / Limestone filler / GGBS (20/50/30) - were studied. A binary binder composed by OPC/Limestone filler (50/50) {L50} was also studied in order to evaluate the impact of high filler content when used without any other pozzolanic SCM. The microstructure was evaluated by the means of TGA and XRD on sound, carbonated and chloride-contaminated cement pastes. Moreover, chloride binding isotherm were measured on cement paste and chloride diffusivity on concrete. Then, carbonation rates were evaluated in accelerated conditions (T=20°C, RH=65% & $[CO_2]$=3%) on concrete specimens. Finally, resistance to external sulphate attacks was assessed in accordance with Swiss standard SIA 292 annex D on concrete containing CEM III/B, OPC/Limestone filler (50/50) and the ternary binder CLS. Concrete containing CLS binder showed a good resistance against carbonation, chloride ingress and sulphate at 20°C when the W/B ratio of the ternary concrete was reduced, despite its higher limestone content. It showed a better durability than the concrete containing L50, which did not contain GGBS. Reducing the W/B ratio of such low-clinker binders and using ternary binder are probably one of the best ways to improve the durability of these systems.

Keywords: Carbonation, Chloride, Sulphate, Limestone, GGBS

Microstructure, deformation and durability of high-strength non-steam-cured concrete with C-S-H seed

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ABSTRACT

The effect of the early strength agent named calcium silicate hydrate polycarboxylate ether nanocomposite (C-S-H seed), fly ash and slag on the development of microstructure, autogenous deformation and durability, as well as the mechanism of interaction between microscopic (e.g., pore structure) and macroscopic properties of concrete, were investigated. Results showed that C-S-H seed increased the compressive strength of concrete before 7 d. The addition of C-S-H seed decreased both relative humidity and capillary pore diameter due to rapid hydration, which resulted in high negative capillary pressure and autogenous deformation of up to 40%. The higher fly ash and slag contents decreased early-age autogenous deformation. Further analysis showed that the addition of C-S-H seed decreased the percentage of pores>1000 nm and the most probable pore diameter of concrete, thus increasing resistance to chloride migration into concrete. The chloride diffusion coefficient was linearly related to the amount of cementitious material together with the water-to-binder ratio. The C-S-H seed decreased the availability of pores of critical diameter (14 nm) of concrete exposed to water freezing, leading to an increase in the freeze–thaw resistance of concrete. In addition, the C-S-H seed also reduced the overall porosity of concrete, leading to an increase in resistance to sulfate attack. Similar trends were observed for increased fly ash and slag content. Besides, the concentrations of AP and Ca^{2+} significantly affected sulfate resistance.

Keywords: High-strength concrete; Non-steam-cured; C-S-H seed; Microstructure; Autogenous deformation; Durability

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Experimental studies on durability performances of ultra-lightweight low-carbon LC^3 cement composites against chloride ingression and carbonation

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ABSTRACT

This study aims to experimentally evaluate the durability performances of a novel ultra-lightweight low-carbon calcined clay cement composite (ULCC-LC^3) for use in sustainable marine concrete. The durability performances of ULCC-LC^3 were characterized by conducting rapid chloride migration tests and accelerated carbonation tests. Results indicate that using LC^3 is beneficial for improving chloride resistance of ULCC-LC^3 due to refined pore structure while the carbonation resistance performance can be reduced due to less content of cement and pozzolanic reaction. The MIP tests showed the effect of using LC^3 on microstructure of ULCC without carbonation was reducing the volume of porosity coarser than gel pores while increasing the volume of gel pores. The cementitious matrix of mixes with LC^3 was significantly densified by carbonation.

Keywords: Ultra-lightweight, Low-carbon, LC^3 cement, Durability, Chloride ingression, Carbonation

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Deterioration of an existing concrete structure exposed to industrial flue gas

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ABSTRACT

This paper presents the results of a 10-year experimental study on concrete structures exposed to industrial acidic flue gas environments. Six cylindrical concrete samples were drilled along the height direction. Changes in compressive strength, carbonation depth, pore structure, ion concentration, pH, phase composition, substance content, and morphology of concrete with sampling height and exposure depth were tested, and the degradation law and corrosion mechanism were studied at macro-micro levels. The test results show that the carbonation depth of the top concrete is 1.4 times that of the bottom, while the compressive strength decreases by 12 MPa. With the increase of sampling height, the porosity of concrete gradually increases, pH decreases, and sulfate ion concentration increases. With the increase of exposure depth, the rates of pH increase and sulfate ion concentration decrease are initially rapid, then slow, and finally tend to stabilize. Concrete corrosion products AFt and Gyp are mostly produced within the top 10mm depth, while $CaCO_3$ and Gyp coexist in the sulfide-carbonization transition zone, at a depth of around 15mm from the exposure surface. Finally, an improved model for predicting the neutralization depth of concrete is proposed, and the predicted results are in good agreement.

Keywords: Industrial flue gas environment; Concrete; Sulfide; Carbonation; Corrosion mechanism

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Engineered cementitious composites (ECC) with limestone-calcined clay blend for infrastructure durability

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ABSTRACT

Engineered Cementitious Composites (ECC) exhibiting superior crack width control capabilities under tensile loading are a kind of promising construction material for enhancing the durability of infrastructures, as the water and chemical ions transport through fine cracks will not accelerate significantly compared with that in un-cracked status. Limestone-calcined clay cement (LC^3) is a low-carbon material with high chloride resistance, and it is feasible to make low-carbon ECC with LC^3. However, the chloride transport property and the effect of self-healing on the chloride transport for LC^3-based ECC have not been well understood. This study aims to fill this gap, by systematically examining the mechanical properties, chloride diffusivity coefficient, and the self-healing property (in terms of chloride transport property) of a new version of LC^3-ECC with 20% Portland cement, 20% fly ash and 60% limestone-calcined clay. At 28 days, the LC^3-ECC achieved medium compressive strength (37 MPa) and excellent crack width control capacity, with a mean crack width of 50 μm at 1% tensile strain. The chloride diffusivity coefficient of un-cracked LC^3-ECC was as low as 5.57×10^{-13} m^2/s. Under wet-dry cycles, cracked LC^3-ECC showed a self-healing potential even with relatively large cracks (wider than 100 microns). The developed low-carbon ECC can be used as a cover layer to enhance the durability of structures in the marine environment. Moreover, the self-healing efficiency can be incorporated into prediction models for better estimation of the chloride ingression and lifetime and to facilitate the durability design of infrastructure.

Keywords: Engineered cementitious composites (ECC); Limestone calcined clay cement; Durability; Chloride transport; Self-healing

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Microstructure of cementitious materials under the coupling effects of Cl^- and Mg^{2+} in a marine tidal environment

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ABSTRACT

To reveal the deterioration mechanism of cementitious materials serving in the marine tidal environment, this study investigates the microstructures of cementitious materials under the coupling effects of Cl^- and Mg^{2+}. This study mainly analyzes the phase composition, pore structure distribution, and micromorphology of the hardened cementitious materials with 30 % fly ash (FA), 30 % ground granulated blast furnace slag (GGBS), or a combination of 15 % FA and 15 % GGBS under different Mg^{2+} concentrations. The effects of Mg^{2+} concentration and mineral admixture type on chemically bound chloride ions and their microstructures are investigated. The results show that a large amount of Friedel's salt is formed under the coupling effects of 0.6 mol/l Cl^- and 0.1 mol/l Mg^{2+}. A corrosive solution with a high concentration of Mg^{2+} is not conducive to the forming of Friedel's salt. In a Cl^- or Cl^- -Mg^{2+} environment, GGBS can chemically bind more chloride ions than FA. With the increase of Mg^{2+} concentration, more pores and cracks appear on the sample surface. In a Cl^- -Mg^{2+} corrosive solution, cementitious materials with mineral admixtures are more porous than pure cementitious materials. Cementitious materials hardened with GGBS are more porous than those materials hardened with FA. Thus, GGBS is more conducive to improving the materials' resistance to chloride ions than FA.

Keywords: Chloride ion; Magnesium ion; Cementitious materials; Microstructure; Tidal zone

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ORAL PRESENTATION
- Life cycle assessment
(Session C5)

Deterioration mechanism and prediction model of sulfur dioxide attack on concrete in complex industrial environments

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ABSTRACT

In the electric power, metallurgy, and chemical industries, industrial production emits a large amount of SO_2, accompanied by high temperature and high humidity. This results in severe durability damage for concrete structures in complex industrial environments. In this study, the SO_2 attack test method of concrete was proposed, and the variations of neutralization depth, physical and mechanical properties, and ions concentrations were analysed. Moreover, the phase composition, micromorphology, and pore structure of concrete were determined by XRD, TG, SEM, and MIP, revealing the deterioration mechanism of concrete subjected to SO_2 attack. The results indicated that increasing the exposure time could increase the neutralization depth and mass, and the maximum compressive strength loss was 18.80% at 20 days. The ions concentrations changed significantly with increasing exposure time, and the pH and SO_4^{2-} concentration in the surface layer of concrete were 3.90 and 26.98% at 20d, respectively. The attack product of ettringite appeared near the hydration products in the initial stage. Due to the decrease in the pH of the pore solution, ettringite was decomposed to produce gypsum. An increase in the exposure time could result in an increase in the gypsum content. Finally, the mass balance equations of SO_2 and sulfurable substances were established. A calculation method of SO_2 diffusion coefficient was proposed, and the prediction model of neutralization depth of concrete was obtained by using the dimensionless method.

Keywords: Sulfur dioxide, Concrete, Performance evolution, Deterioration mechanism, Neutralization depth model

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Life cycle assessment of environment-friendly polycarboxylate superplasticizer for concrete

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ABSTRACT

With the rapid development of the construction industry, it is necessary to synthesize environment-friendly chemical admixtures, especially under the background of the global "low-carbon" strategic goal. In this study, a novel solid-state polycarboxylate superplasticizer (PCE) with low energy-consumption was designed and synthesized, and the environmental impact was quantified. In industrial application, solid-state PCE exhibited higher cement paste fluidity and concrete slump as compared to liquid-state PCE. Importantly, a life cycle assessment (LCA) on the PCE synthesis, the packaging materials used, and the transportation of PCE was performed based on the "cradle-to-gate" approach. The results showed that solid-state PCE had a lower environmental impact (<40%) compared to liquid-state PCE. The largest environmental impact was due to the production of PCE (materials used and power consumption), followed by the packaging and transportation of PCE (lower impact for packaging solid-state PCE in plastic woven bags). In addition, the damages to Human Health, Ecosystems, and Resources from solid-state PCE (13%, 32% and 35%, respectively) were lower than those from liquid-state PCE (87%, 68% and 65%, respectively). The databases and inventory data that are associated with the production of the superplasticizer are disclosed for the first time, facilitating the environmental impact analysis and life cycle assessment of the superplasticizer production process.

Keywords: Polycarboxylate superplasticizers; Life cycle assessment; Environmental impacts; Low-carbon; Solid-state

Prediction of leaching risk in waste-based lightweight aggregates

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ABSTRACT

Manufacturing of lightweight aggregates (LWAs) is an important protocol to safely recycle contaminated solid waste. However, the lack of safe immobilization technology for heavy metals severely limits the popularization and application of LWAs. To address the problems of high fluctuation in raw material components and the high risk of heavy metal leaching in solid waste-based LWAs, this study built a prediction model for the leaching risk of LWA made from solid waste. To provide a compressive dataset, all the heavy metal leaching data generated in this study were synthesized. Through various analytical methods, including linear regression, empirical modelling, and machine learning, an intelligent component design scheme for heavy metal efficiently immobilization LWAs was formulated. Furthermore, a rapid predictive model for assessing the component and leaching risk of solid waste-based LWAs was established. This research provides theoretical and technical support for advancing the utilization of solid waste resources.

Keywords: Leaching risk; Prediction model; Machine learning; Solid waste; Lightweight aggregate

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Towards net zero carbon emissions in the south African cement and concrete construction industry – challenges and opportunities

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ABSTRACT

South Africa has committed to achieving net-zero greenhouse gas (GHG) emissions by 2050. This commitment requires concerted and sustained effort of different stakeholders including the building and construction (B&C) sector. Thus far, a number of strategies have been proposed and, in some cases, implemented in the B&C sector in a bid to reduce GHG emissions. Some of these include, the use of supplementary cementitious materials, low clinker concretes and progressive adoption of performance-based structural and durability design of concrete structures. However, these strategies will not necessarily result in net-zero GHG emissions if not well co-ordinated, monitored and assessed. In a developing country like South Africa, several socio-economic factors, some mutually inclusive, have to be considered in the development of short-, medium- and long-term net-zero target strategies. This paper explores the challenges and opportunities that are faced by the South African cement and concrete construction industry as it forges ahead towards a net-zero target by 2050 and beyond.

Keywords: Decarbonisation; Greenhouse gases; Low carbon cement; Sustainable environment; Low carbon concrete

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A multi-scale approach for assessing the robustness of cement-based materials from a yield stress perspective

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ABSTRACT

Yield stress is a crucial rheological indicator, alongside control parameter for 3D printing,that is affected by changes in the component content of flowable cement-based materials containing multiple components. It is vital to accurately predict the yield stress and evaluate the robustness of fresh cement-based materials (i.e., their ability to maintain consistent properties despite variations in production methods) from both a generic and analytical perspective. We conducted a comprehensive review of key parameters that characterize various component properties, including the thickness of the adsorbed polymer layer, adsorption–desorption kinetics of polymers, particle size and distribution of powders, and packing properties of both powders and aggregates. Subsequently, we investigated the impact of adjusting the component content in cement-based materials containing binary blends of powders on the variation of yield stress. Additionally, we integrated existing analytical models that connect component proportions with yield stress into a multi-scale and physical approach, which we then compared with our experimental yield stress measurements. Furthermore, we utilized the derived analytical relationships to evaluate the robustness index of the parameters at a given standard variation of each raw component content, enabling us to map the most sensitive variations in terms of yield stress onto component dosage. Our results suggest that the proposed approach can effectively predict variations in the yield stress of cement-based materials containing multiple types of powders by considering the packing properties, particle size distribution, and chemical characteristics of polymers. We also proposed a comprehensive framework outlining the influence of component properties on the robustness of cement-based materials, based on the robustness index maps of each key parameter. This framework provides valuable guidance for designing resilient cement-based materials using readily available raw materials.

Keywords: Rheology, Yield stress, Robustness, cement-based materials, 3D printing

ORAL PRESENTATION
- Waste utilisation 2
(Session A6)

Utilisation of phosphogypsum in green building materials: from bio-treatment to functional materials

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ABSTRACT

Utilising phosphogypsum (PG), a solid waste produced by phosphorus chemical enterprises, in building materials, is of great significance to environmental protection and promote the reduction of PG solid waste. However, compared to the traditional approaches, the further utilisation still facing lots of problems, for example, the uncontrolled property due to eutectic phosphate impurity in PG, the poor water resistance of PG, and low-quality utilisation of PG etc... To solve the abovementioned issues, a series of research should be conducted. This paper introduced the preliminary attempts from Yunnan University in improving the green utilisation of PG, including, the bio-treatment to reduce eutectic phosphate, the preparation of hydrophobic phosphogypsum, and the manufacture of low-carbon cementitious materials by PG and solid waste. The results showed that, bio-washing of PG could lead to the carbonation of phosphogypsum and the removal of eutectic phosphorus impurities within the gypsum lattice. Meanwhile, the residue bacteria in PG can be further used for self-healing process. Moreover, the hydrophobic modification of PG changed its hydrophobic performance, which was confirmed by water contact angle increasing from 0° to 147°. Finally, the early hydration of phosphogypsum-steel slag cement was influenced by the finesses of stell slag and treatment of PG, and the application of early age carbonation process could provide better the reactivity of steel slag and improve the mechanical propertied of cement. Those attempts could provide a promising way to utilising the phosphogypsum in green building materials.

Keywords: Self-healing; Phosphogypsum; Cold-bonded; Artificial Aggregate; Cracking

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Preparation of low-carbon mine filling materials from lead smelting slag excited by alkaline calcium-magnesium components

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ABSTRACT

The pressing need for ecological sustainability necessitates the recycling of Lead smelting slag (LSS) obtained from traditional lead and zinc pyrometallurgy. This is because the presence of heavy metals (Cr, Ni, Cu, Zn, As, and Pb) in LSS poses a harm to human beings. This paper explores the production of ecological cementitious materials by including small quantities of cement clinker (CC), lime ash slag (LAS), slag powder (SP), and bischofite (BF) to enhance their reactivity. To create the unclassified tailings sand (UTS) mine cemented backfill materials (MCBM), the prepared cementitious materials were combined with tailing sand. The findings indicate that the most effective proportion of binder composition by mass is 46% for LSS, 20% for LAS, 13% for SP, 17% for CC, and 4% for BF. At this ratio, the compressive strengths of the specimens after 3, 7, and 28 days are 11.1 MPa, 16.9 MPa, and 24.2 MPa, respectively. The backfill slurry, consisting of a binder-sand ratio of 1:2 and a solid content of 74%, exhibits a fluidity of 259 mm and a 28-day compressive strength of 5.48 MPa. These characteristics satisfy the criteria for high-strength grade MCBM suitable for self-weight backfill. The findings from the MIP analysis indicate that as the cement-sand ratio increases, there is a corresponding increase in the relative number of non-detrimental pores and the mechanical properties of the infill also improve. An increase in the cement-sand ratio will result in the hydration products being denser, hence enhancing the encapsulation of tailings. The solidification ratio of the MCBM for each heavy metal exceeds 70%, and the leaching of heavy metals conforms to the Chinese Class IV groundwater standard.

Keywords: Lead smelting slag; Filling material; Mechanical properties; Fluidity; Heavy metal leaching

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Effects of wood waste bottom ash (WWBA) and fly ash (FA) on the properties of concrete

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ABSTRACT

Wood waste bottom ash (WWBA) is produced in thermoelectric or small industrial furnaces. Wood processing residues, a sustainable and renewable source of energy production, generate a large amount of wood waste ash. The amount of wood waste ash increases with the growing demand for bioenergy production. The main concerns related to this ash are storage, disposal, utilization and the presence of unburnt carbon. Power plants that produce heat and electricity create combustion by-products. These products include fly ash (FA), slag, carbon dioxide and other compounds. FA that is not suitable to be reused in construction products, such as concrete, is stored in landfills. With extended urbanisation and rapid growth of construction industry, the demand for cement and aggregates, especially for the production of concrete, is increasing. Therefore, this study focuses on the use of bottom ash as a substitute for aggregate and fly ash as a substitute for cement in concrete mixes. This study aims to investigate the effect of FA and WWBA on the physical and mechanical properties of cement concrete and to evaluate the possibility of replacing part of the cement and sand in the mixes with ashes. Five concrete compositions were prepared using CEM II/A-LL 42.5 N cement, 0/2 sand, 5/16 granite crushed stone, polypropylene fibre, and superplasticizer. The 0/2 fraction sand was replaced by WWBA and the cement was replaced by FA in amounts of 0%, 2.5%, 5%, 10% and 15% by mass. The following concrete properties were tested and analysed: mixture density, flowability, density of concrete samples, compressive strength and ultrasonic pulse velocity. Analysis of the test results showed that 5% was the most suitable and useful ashes content for the preparation of concrete.

Keywords: Wood waste bottom ash; Fly ash; Cement concrete; Physical and mechanical properties

Enhancing coal gangue aggregates with fly ash-cement slurry: synergistic effects of CO_2 mineralization on physical and mechanical properties

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ABSTRACT

The application of coal gangue in construction materials faces challenges due to its inherent structural looseness, elevated porosity, and high carbon content. This study encapsulated coal gangue aggregates (CGAs) with a fly ash-cement slurry, varying the content of fly ash (0%, 10%, 20%, and 30%) and maintaining a water-to-cement ratio of 0.35. These aggregates were subjected to a curing process within an environment containing a CO_2 concentration of 20%, 0.1 MPa pressure, 70% humidity, and a temperature of 20 °C. The study delved into examining how the combination of fly ash-cement slurry encapsulation and CO_2 mineralization impacts the physical properties and microstructure of CGAs, focusing on understanding the influence and mechanism behind the synergistic effects. Findings reveal that following the encapsulation process using a fly ash-cement slurry, CGAs exhibit a higher apparent density, a reduced crushing value, but a notable increase in water absorption rate. Notably, treatment with 10% fly ash-cement slurry and CO_2 mineralization increased the apparent density by 3.85%, reduced the crushing value by 39.57%, and limited the increase in water absorption rate to 9.9%. Additionally, the elastic modulus of the enhanced aggregates rose by 12.73%. This can be attributed to the formation of a significant quantity of C-S-H gel and $CaCO_3$ products as a result of the interplay between the encapsulated fly ash-cement slurry and CO_2 mineralization. This process effectively occupied the voids within the coal gangue. Consequently, CO_2 mineralization enhanced the interfacial transition zone between the slurry and coal gangue, ultimately leading to improved coal gangue's mechanical performance.

Keywords: Coal gangue aggregate; Fly ash-cement slurry; CO_2 mineralization; Synergism; Physical properties

ORAL PRESENTATION
- Durability 2 (Session B6)

Preparation of high cracking-resistance dam concrete with expansive low-heat Portland cement and applications in Baihetan and Wudongde arch dams

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ABSTRACT

Low-heat Portland cement (LHPC) concrete contributed to zero cracks in Baihetan and Wudongde arch dams in China, demonstrating the excellent cracking resistance of LHPC concrete and great application potential in massive concrete structures. However, the long-term property of low-heat Portland cement concrete is very important and hasn't been revealed yet. In this study the evolution of properties of low-heat Portland cement concrete specimens as well as cores cured under standard curing and outdoor conditions were systematically examined. The results showed that under both curing conditions the mechanical properties of low-heat Portland cement concrete increases with the curing age and the freeze-thaw resistance and anti-permeability were excellent. With the increase of age, the hydration degree, the cement hydration products including C-S-H, CH are increasing, leading to a reduction in porosity and a denser concrete structure. It indicates that the low hydration heat and slow hydrating rate of low-heat Portland cement concrete result in the higher density in concrete matrix, which is the key factor to the higher performance. Additionally, the relations between the macroscopic performance and microstructure were established, providing a theoretical basis for predicting the service performance development.

Keywords: Low-heat portland cement; Dam concrete; Long-term property; Microstructure

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Enhancing fiber-reinforced asphalt binders via surface grafted: A novel interfacial modulation strategy for durability improvement

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ABSTRACT

Interfacial modulating strategy is acknowledged as a potent technique for enhancing the properties of binding materials, aligning with sustainable and low-carbon technology goals. In this study, graphene oxide (GO) nanosheets were attached and grafted onto the surfaces of polyester (PET) and polyacrylonitrile (PAN) fibers to improve the durability and performance of asphalt binders. The chemical conformation, microstructure, and morphology of both the original and modified fibers were thoroughly examined using Fourier transform infrared spectroscopy and scanning electron microscopy. These analyses confirmed the successful implementation of surface activation and GO grafting. The rheological properties of the binders, assessed using a dynamic shear rheometer (DSR), showed that binders with GO-modified fibers offer superior high-temperature rutting resistance and improved anti-fatigue properties compared to binders reinforced with unmodified fibers. These improvements in rheological and mechanical performance are due to the increased roughness and modulus with GO grafted, which effectively improves stress transfer of the interfaces between the fibers and asphalt, thereby contributing to the advancement of low-carbon paving technologies.

Keywords: Fibers reinforced asphalt; Graphene oxide; Surface modification; Rheological properties; Modification mechanism

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Methods for determining freeze resistance material parameters of concrete in different freeze-thaw media environments

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ABSTRACT

The freeze-thaw fatigue damage equation for concrete was derived. The relationship between the concrete material parameter (β) and the freeze-thaw life of concrete was established. Utilizing the freeze-thaw fatigue damage equation and lots of literature data on freeze-thaw cycle test of concrete, the relationship between the β value and concrete water-binder ratio (w/b), air void content (A), and compressive strength (f_{cu}) of concrete was established. Under freeze-thaw conditions, the β value of concrete exhibited a linear relationship with its w/b, A, and f_{cu} value. The β value of concrete decreased with an increase in its strength. A higher air void content in concrete corresponded to a lower β value. The β value increased with an increase in the water-binder ratio. Studying the β value enables the prediction of concrete's laboratory freeze-thaw life, and lays the groundwork for subsequent predictions of its outdoor freeze-thaw life.

Keywords: Freeze-thaw fatigue damage equation, Concrete material parameters, Concrete freeze-thaw life, Salt freeze, Correlations

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Cracks development and strain field of concrete under multi-axial stress conditions

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ABSTRACT

The cracks development of concrete under multiple stress states is complicated because the triaxial stress on the heterogeneous concrete affects mesoscale interactions between aggregates and mortar, which further alters the internal damage evolution of concrete and its load bearing mechanism. Hence, probing the internal cracking evolution of concrete under a complex stress state is the key to better understanding the characteristics and failure mechanism of concrete material. This study conducted a series of X-ray computed tomography (X-CT) tests on fiber-reinforced polymer (FRP) confined concrete with varied in situ axial load levels. Different cross-sections of concrete specimens—circular, square with round corners, and square with sharp corners—were designed to achieve uniform or nonuniform passive confinement conditions. The obtained volumetric images from X-CT clearly exhibited the internal cracks development of concrete, where crack forming, crack growth, and failure localization were displayed for the concrete under varying triaxial stress states. The development of damage to concrete due to cracking with increasing load was also quantified by image segmentation. In addition, the digital volumetric correlation technique (DVC) was employed to produce the volumetric displacement field and strain distribution in the confined concrete according to the image variation of natural speckles. A three-dimensional internal strain analysis revealed that strain localization was mainly caused by mesoscale concrete heterogeneity and nonuniform confinement. More importantly, this study provides the first database of full-field strain tensors for FRP-confined concrete under different axial load levels. These data are valuable for the development of concrete mechanics, failure criteria of materials, and computational modeling of concrete materials and their structures, especially for concrete under complex stress states.

Keywords: Concrete; Crack development; Multi-axial stress conditions; X-ray computed tomography; DVC

ORAL PRESENTATION
- Durability 3 (Session C6)

Multi-scale prediction model of ion diffusion in concrete based on effective medium theory

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ABSTRACT

A novel approach to estimate the effective ion diffusivity of concrete is introduced in this paper. The ion diffusivity in pore solution is calculated considering the effect of multi-ion diffusion. Based on effective medium theory, a multi-step nested model for diffusion prediction was proposed considering the characteristics of its constituent phases from micro to macro scale. The GEM equation was applied to homogenize the ion diffusion in pore at the micro-scale into diffusion coefficient of cement phase. At the microscopic scale, the ITZ phase and aggregate phase were combined using Maxwell–Garnet relationship, and the effective ion diffusivity was determined by considering concrete as Bruggeman symmetric media. The model was validated by existing experimental data and compared with other diffusion models. The results show that the proposed model improve the prediction accuracy of ion diffusivity compared with previous models, which provides theoretical guiding to the durability design of practical concrete structure.

Keywords: Concrete; Diffusivity; Effective media theory; Multi-scale; Prediction model

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Structural features of initial micro-cracks in low-heat Portland cement dam concrete cured in simulated xerothermic conditions

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ABSTRACT

Wudongde ultra-high arch dam is located in the xerothermic valley of Jinshajiang River. It's a challenge to build such a complicated arch dam with low-heat Portland cement (LHPC) concrete in such severe environmental conditions, such as dryness, hotness, strong wind and large daily temperature difference. Large concrete test blocks with 0.45 m in side length were produced and exposed to simulated xerothermic conditions after being cured for different ages. Quantitative microcrack analyses were performed on the cores drilled from the blocks. Structural characteristics of microcracks in the concrete core slices and the evolution of microcracks with curing age were studied. The results showed that the initial micro-crack density in the surficial layer of LHPC concrete blocks decreases with the increase of curing age, and the microcrack density tends to be stable after being cured for over 60 days. The initial microcracks in the concrete slices are mainly located in the interfacial transition zone (ITZ). Thus we suggest curing age of LHPC concrete should be no less than 60d to guarantee the performance of the concrete as well as the safety of Wudongde arch dam.

Keywords: Xerothermic valley, Low heat Portland cement, Concrete, Initial microcrack, Curing age

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Effects of relative humidity and temperature on carbonation dynamics of lime and slaked lime

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ABSTRACT

The carbonation of mineral oxides/hydroxides like lime and slaked lime holds promise for the creation of net-neutral or net-negative carbon construction materials, providing a sink for atmospheric CO_2 in the process. The carbonation extent and kinetics are influenced by factors equally dependent on the base material physicochemical properties and the conditions employed for carbonation. Optimizing these conditions and understanding the instantaneous carbonation mechanisms are the premises for a fast carbonation process.

In this work, we tested the hydration of CaO and subsequent carbonation with different sizes and surface areas at various relative humidities and temperatures. We found that a smaller size and a higher particle surface area can enhance the reaction kinetics and carbonation extent, respectively. Higher relative humidity (~60%) and higher temperature (40~60 °C) can improve the carbonation degree. However, high levels of relative humidity and temperature influence the diffusion and solubility of CO_2, respectively. The carbonation mechanisms were studied by in situ Raman during the reaction process. This study provides detailed methodologies for studying the carbonation process and unveils the reaction mechanism, which is of significant importance for both academic and practical applications.

Keywords: Carbonation; Construction materials; Kinetics

Bond behaviour of FRP bars in ultra-high performance sea-sand concrete

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ABSTRACT

In response to the shortage of river sand, non-desalted sea-sand has been used in ultra-high performance concrete (UHPC), leading to sustainable sea-sand UHPC (UHPSC). Steel reinforcements can not be used in UHPSC due to corrosion concerns. The use of high strength and corrosion-resistant fibre reinforced polymer (FRP) bars as reinforcements in UHPSC offers a viable solution. This paper presents an experimental study on the bond behaviour between FRP bars and UHPSC using direct pullout tests. Various compressive strength of concrete and five types of FRP bars were tested. All specimens failed by pulling out along the internal surface at the outer-grained layer of the bars. The test results show that the bond strength of FRP bars in UHPSC is not related to the compressive strength of concrete, but is influenced by the fibre type and horizontal shear performance of the FRP bars.

Keywords: Ultra-high performance Sea-sand concrete; FRP bar; Bond performance

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STUDENT COMPETITION
(Session SC-A1)

Enhancing passivation of mild steel in M-S-H binder with sodium hexametaphosphate

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ABSTRACT

Magnesium silicate hydrate (M-S-H) based binder has shown promising strength and overall performance, but their lower pH compared to Portland cement has restricted their use to certain applications. To increase the feasibility of using these binders in structural applications involving steel reinforcement, the resistance of these samples against corrosion needs to be investigated. Sodium hexametaphosphate (SHMP), commonly used as a plasticizer to enhance the workability of M-S-H mixes, has the potential to increase the pH of the system. This study investigated the changes in the passivation of steel in M-S-H mixes involving the use of SHMP. The electrochemical impedance spectroscopy assessment of steel in M-S-H shows increased corrosion resistance with inclusion of 3%SHMP compared to samples without SHMP. With SHMP incorporation, mild steel rebar demonstrates sufficient passivation in the investigated M-S-H mixes. These results could provide valuable insights into expanding the use of M-S-H systems in structural applications.

Keywords: M-S-H; MgO-binders; SHMP; Passivation; Corrosion

Sulfate resistance of carbonated basic oxygen furnace slag-metakaolin-Portland cement blends

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ABSTRACT

Basic oxygen furnace slag (SS) is prone to carbonation due to its alkaline properties. The combined use of carbonated basic oxygen furnace slag (CSS) with metakaolin (MK) as a composite supplementary cementitious material (CSS-MK) can improve the reactivity of CSS and significantly lower the overall embodied CO_2 emission. This study aims to clarify the influence of CSS-MK on the resistance of cement to ESA. Transport property before ESA, and macro-scale expansion, microstructure, and evolution of phase assemblage during ESA were investigated. Results indicate that CSS-MK reduces water absorption by 37.9% and electrical flux by 67.6%, enhancing transport property and reducing sulfate ion intrusion into the cement paste. Meanwhile, the reaction in CSS-MK blends between the $CaCO_3$ in CSS and MK consumes $Ca(OH)_2$, forms ettringite and thermodynamically more stable carboaluminate, and results in the absence of monosulfate prior to ESA and the presence of carboaluminate during ESA, which consequently decreases ettringite content by 40% in paste after 240 days of ESA. Furthermore, at the macroscopic level, the expansion decreased by 85.2% after 360 days of ESA, effectively mitigating specimen cracking and damage.

Keywords: Basic oxygen furnace slag; Carbonation; Metakaolin; External sulfate attack

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Influence of clay calcination methods on sulphate optimisation of calcined clay blended cements

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ABSTRACT

The present study aims to understand the effect of clay calcination methods on the sulphate optimisation of calcined clay-blended cement systems. Two calcination techniques were employed, namely rotary calcination and flash calcination, to calcine the clay and the resulting calcined clays were then used to replace 30% of Portland cement clinker. Gypsum was used to provide the sulphate source and the sulphate content was varied from 0% to 3.5% in 0.5% increments. Isothermal calorimetry was conducted over 72 hours to study the hydration kinetics of these blends at different sulphate levels. Additionally, ion chromatography was used to measure the dissolved sulphate ions from clinker, calcined clay, and gypsum, which was used to calculate the optimal sulphate content in the blends. Hardened cement pastes were further characterized using X-ray diffraction and thermogravimetric analysis at 7 days.

Calorimetry results indicated that at the same sulphate level, under undersulphated conditions, blends with flash-calcined clay showed a higher hydration peak, whilst under properly sulphated and supersulphated conditions, blends with rotary-calcined clay exhibited a higher peak. Additionally, at the same sulphate level flash-calcined clay blends displayed a significant delay in aluminate hydration compared to rotary-calcined clay blends, and this delay increased with increasing gypsum content. Analysing these results, along with the larger specific surface area of rotary-calcined clay, The higher sulphate demand of the rotary-calcined clay could be attributed to the higher pozzolanic reactivity of rotary-calcined clay as compared to the flash-calcined clay. In addition, the larger specific surface area resulting from rotary calcination may also lead to more sulphate ions being adsorbed onto the surface layer, making them unavailable for the reaction with aluminates.

Keywords: Calcined clay; Flash calcination; Hydration; Rotary calcination; Sulphate addition

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The influence of different sulfate sources on belite hydration

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ABSTRACT

Belite, as a significant cement mineral, has been known for a long time, since the invention of cement by Joseph Aspdin, and is the precursor of alite. Moreover, belite was also found in Roman historical binders. However, the properties of pure belite have not been sufficiently studied, mainly due to the low hydration rate of β-belite, which is found in ordinary Portland cement. Recent studies demonstrated the high chemical activity of α-belite polymorphs, which renewed the research interest in the hydration of belite. Previous research revealed that sulfates significantly affect pure belite's hydration, but only calcium sulfate was studied as a source of sulfate. The present study examined the effect of various sulfate sources, such as sodium, potassium, and magnesium sulfates, on the hydration of α-belite. The hydration rate, the mineral composition of hydrated belite, and mechanical properties were studied using isothermal Calorimetry, X-ray diffraction in conjunction with thermogravimetric analysis, and ultrasonic pulse velocity test, respectively. Results show that the source of sulfates significantly affects not only the rate of hydration but also the mechanical properties of belite paste.

Keywords: Belite; Hydration; Mineral composition; Mechanical properties

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Optimization of initial porosity and influence on carbonation behavior of γ-dicalcium silicate

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ABSTRACT

Carbonation curing of low-carbon clinker presents an environmentally beneficial approach to reducing cement industry emissions. The carbonation behaviors of low-carbon clinker largely depend on initial porosity, where lower porosity advantages compressive strength development but hinders carbonation. This study aims to optimize the initial porosity of γ-C_2S compacts to improve mechanical performance and accelerate the carbonation reaction. Carbonation properties including carbonation degree, compressive strength, phase composition, and microstructure of γ-C_2S compact fabricated with varying initial voids ratios (achieved through different water-solid ratios and compaction pressures) were studied. Results indicated that a higher voids ratio with adequate water was conducive to the reaction, while a lower initial voids ratio with sufficient carbonation was beneficial for the enhancement of compressive strength. Specifically, the γ-C_2S compacts fabricated with a water-solid ratio of 0.110 and initial void ratio of 45% exhibited the highest compressive strength (102 MPa) and optimum carbonation degree (43%) for 2 h accelerated carbonation curing. An interconnected product layer deposited on the γ-C_2S particles was observed reducing the voids ratio while inhibiting the further reaction.

Keywords: γ-C_2S; Accelerated carbonation; Initial porosity; Compressive strength

Evaluating the influence of elevated temperatures on mechanical properties of fly ash based concrete

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ABSTRACT

Ordinary Portland Cement (OPC) has a vast usage in the construction of modern infrastructure. However, production of OPC leaves behind a huge carbon footprint and generates excessive greenhouse gases, rendering the material unsafe for the environment. This problem could be mitigated by replacing OPC with more environment-friendly materials like fly ash, which is not only an inexpensive cementitious material but can, also dispose of industrial waste generated from thermal power plant. Fire is one of the most damaging hazards, which brings loss to both life and property. It can affect structures, including those made of concrete. Understanding the behaviour of concrete at elevated temperatures helps in assessing its fire resistance and designing structures that can withstand fire events. By studying concrete under such conditions, researchers can evaluate its thermal properties, mechanical strength retention, spalling tendency, and overall fire performance. The present study aims in comprehending the effect of elevated temperature on the mechanical strength of fly-ash blended concrete with a variation of 0%, 10%, 15%, 20%, 25% and 30%. The mix design uses the k- factor or the cementing efficiency of fly ash which reduces the consumption of OPC. The specimens were exposed to elevated temperature following the ISO 834 standard fire curve. It is observed that addition of fly ash enhances the mechanical properties of concrete which when exposed to high temperature.

Keywords: Elevated temperature; Fire; Fly ash; Mechanical properties; Ordinary Portland cement

Effect of microwave curing on the microstructure and mechanical properties of steel-concrete interface

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ABSTRACT

Precast concrete is popular due to its high production efficiency, fast delivery, and environmentally friendly nature. However, to ensure its production efficiency, achieving high early strength in a short period of time is crucial for precast concrete. Whist steam curing is the most widely used accelerated curing method to increase early strength of concrete in precast industry, it has several drawbacks, such as long process time, high energy consumption, and reduced long-term strength of concrete. Additionally, it could also increase the carbon footprint of the final concrete products. To address these issues, microwave curing has been proposed as a potential alternative due to its high heating efficiency, energy saving, and non-polluting nature. However, due to the potential interactions between microwave and reinforcing steel, concerns have been raised over the potential influence of microwave curing on the microstructure and mechanical properties of steel-concrete interface (SCI).

This research, therefore, investigates the effect of microwave curing on the microstructure and mechanical properties of SCI in comparison with the SCIs formed under steam curing and normal curing. Reinforced concrete samples reinforced with two types of steel bars (plain and ribbed) with different diameters (12 mm and 16 mm) were subjected to three different curing methods, namely, microwave, steam, and normal curing methods. The temperature development during the curing process was monitored using Fiber Bragg Grating (FBG) sensors and a thermographic camera. Compressive strength tests and pull-out tests were conducted to assess the bond strength between the rebar and concrete. Scanning electron microscopy and microhardness tests were also used to characterise the microstructure and micro-mechanical properties of SCI.

The results show that the bond strength under microwave curing was relatively lower than that of steam curing, although the compressive strength was higher. The bond strength of ribbed bar was much higher than that of plain bars, which was due to the strong mechanical interlock provided by the ribs. On the other hand, the bond strength of the reinforcing steel with larger diameter was lower due to increased weak zones. Micro-level analysis revealed that the interfacial transition zone (ITZ) within the concrete around the reinforcing steel in microwave-cured samples was larger, and the microhardness values within this area were also lower compared to steam curing. Additionally, more surface cracks at the SCI were observed with microwave curing. Based on these observations, it can be tentatively concluded that microwave curing could potentially weaken the bonding between the steel bar and the surrounding concrete which could be attributed to the volumetric heating mechanism and higher temperature rising rate (1℃/min) of microwave curing, leading to a strong expansion of water and air at the SCI.

Keywords: Bond strength; Microwave curing; Micro-hardness; Steam curing; Steel-concrete interface

The effect of incorporating glass waste powder on the performance of industrial residue-based geopolymer

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ABSTRACT

In order to reduce CO_2 emissions and recycle industrial residue, there has been a strong effort in recent decades to create sustainable alternative building materials called geopolymer, an activated aluminosilicate material. Pozzolanic minerals found in industrial waste satisfy the aluminosilicate needs for creating geopolymers. The residues, such as fly ash, bauxite residue, and blast furnace slag, are used to make geopolymer. To develop geopolymers with good properties, more semi-crystalline and amorphous materials are needed. This study presents the effect of glass waste, a municipal solid waste in amorphous powder form, as a partial substitution in the fly-ash and bauxite residue geopolymer systems. Geopolymer was synthesized by mixing glass waste, fly ash, bauxite residue, and light aggregate with sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) as an alkali-activator solution. The mixture was poured into a cylindrical mould, cured at 80 °C for 24 hours, and subjected to ambient curing for 7 and 28 days before compressive strength measurement. The freeze-thaw resistance was measured by the mass loss change after 25 cycles. Partial substitution of fly ash with glass waste in a certain amount increased the compressive strength of the geopolymer and affected mass loss after the freeze-thaw cycle. Glass powder, with its bigger size and smaller surface area than fly ash particles, can act as microaggregates in the system, increasing the strength caused by particle compaction. This also increases the freeze-thaw resistance through the formation of a strong Si-O-Si bond. A scanning electron microscope (SEM) test was conducted to study the homogeneity of structure and the morphology of geopolymer.

Keywords: Geopolymer; Glass waste; Bauxite residue; Fly ash; Freeze-thaw

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Effect of recycled materials and curing conditions on the properties of ultra-high performance geopolymer concrete

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ABSTRACT

The present study examines the potential of using different recycled and industrial by-products for the manufacture of Ultra-High Performance Geopolymer Concrete (UHPGPC) to provide a more sustainable solution for the development of concrete structures with exceptional short- and long-term mechanical performances. Clean and recycled foundry sand, silica fumes, and GGBS are used to develop the UHPGPC matrix, while the reinforcement comprises short recycled steel fibres. Several trial mixes with varying contents of the main constituents are examined in terms of fresh and hardened properties, and the effect of curing temperature on compressive strength is also investigated. The results revealed that recycled tyre steel fibres help to increase the 7-day compressive strength up to 136 MPa. The application of recycled foundry sand affects the workability and compressive strength, but only to a limited extent. Significantly, the incorporation of silica fume enhances the 7 day compressive strength due to increased pozzolanic activity and refined pore structure. This paper also discusses the impact of different curing temperatures on the geopolymerization process. Though higher temperatures accelerate strength development, there is need to control to minimise the resulting micro-cracking. This study confirms that it is possible to incorporate sustainable elements in UHPGPC formulations that have the potential for larger building applications. It lays the groundwork for future research into the long-term durability and optimisation of UHPGPC blends adapted to specific environmental conditions and structural needs.

Keywords: Ultra-high performance geopolymer concrete, Foundry sand, Curing temperature, Recycled tyre steel fibres, Silica fumes

Introducing diffusion model to analyze the lifecycle GHG emissions of alternative cementitious materials used for concrete elements production

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ABSTRACT

The utilization of alternative cementitious materials is an effective way to reduce greenhouse gas (GHG) emissions during concrete production. life cycle assessment(LCA) studies for concrete produced with alternative cementitious materials often neglect the carbonation during the service stage of the concrete elements. Thus a diffusion model is introduced to quantify the CO_2 sequestration potential of several concrete elements. In this study, CO_2 diffusion coefficients of different cementitious materials were obtained from carbonation experiments. The thermodynamic modeling is used to determine the CO_2 absorption capacity. LCA was conducted to analyze the GHG emissions associated with the manufacturing and service phases of concrete elements using different cementitious materials. The results show that the manufacture of cementitious materials constitutes the primary source of GHG emissions in concrete production. The addition of supplementary cementitious materials(SCM) and the utilization of alternative cement both reduce the carbon emissions of concrete. However, this also tends to diminish the amount of CO_2 absorbed during the service phase and LC^3 shows the lowest CO_2 absorption during service life.

Keywords: cycle assessment; GHG emissions; CO_2 sequestration; Diffusion coefficient

STUDENT COMPETITION
(Session SC-B1)

Effect of ultrasonic pretreatment on the hydration and strength development of alkali activated fly ash

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ABSTRACT

As a by-product of coal-fired power plants, a significant amount of fly ash is produced annually, but not as much is consumed. Activating fly ash with highly alkaline solutions to produce an amorphous aluminosilicate gel that has a similar structure to zeolitic precursors is an attractive approach to maximizing the utilisation of fly ash. Traditional thermal curing of alkali-activated fly ash (AAFA) involves simultaneous dissolution and polymerization stages. To enhance the dissolution process, this study employs ultrasonic pretreatment, which has been proven to accelerate dissolution in Portland cement systems.

This research focuses on the investigation of the effect ultrasonic pretreatment on the hydration and strength development of AAFA. In this study, geopolymer is produced using fly ash and sodium hydroxide (NaOH), with combinations of ambient curing (20°C) and ultrasonic pretreatment (20°C) for a total of 2 hours, followed by 24-hour thermal curing (85°C). The results from 1, 7 and 28 days demonstrate an improvement in short-term strength under ultrasonic pretreatment. The XRD results illustrate that no new crystalline phases are formed. The FTIR results also show that under a short period of ultrasound pretreatment, a lower frequency corresponding to the T-O bond is observed, which suggests a contribution of ultrasound in the initial dissolution and diffusion process that results in the formation of an amorphous N-A-S-H gel. Based on the results obtained from this study, the enhanced hydration and increased early-age strength can be attributed to the acoustic cavitation phenomenon of ultrasound, leading to the formation, growth, and collapse of air bubbles in the liquid phase. This could have contributed to the dissolution of fly ash particles and hence enhanced subsequent hydration and strength development of AAFA in early age.

Keywords: Alkali activated fly ash (AAFA), Microstructure, Compressive strength, Ultrasonic pretreatment

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A nacre-inspired calcium silicate hydrate (C-S-H)-based film with high toughness

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ABSTRACT

Cement-based materials are the most widely used and cost-effective artificial material in the world, but the problem of brittleness greatly limits their applications. Calcium silicate hydrate (C-S-H) is the primary hydration product and its inherently disordered packing is considered to be a fundamental source of the brittleness. In this work, a multi-layered C-S-H-Polyvinyl Alcohol (PVA) film was fabricated utilizing a simple vacuum filtration method, exhibiting a soft/hard phase alternating, and hierarchically ordered microstructure. Compared with conventional C-S-H and fiber-reinforced cementitious composites, a substantial improvement on tensile strength, ultimate strain and toughness by 1-2 orders of magnitude was achieved by multi-layered structure, especially reaching ultra-high toughness (19.69 $MJ \cdot m^{-3}$), outperforming nacre by a factor of over ten.

Keywords: Cement; Calcium silicate hydrate; Toughness; Nacre-inspired

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Strengthening mechanisms of sprayed concrete containing accelerator: in the presence of C-S-H nano-seeds

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ABSTRACT

Shotcrete is a pivotal material in tunnel construction, as the process frequently encounters extreme conditions such as karst water and geothermal environments, which impose rigorous demands on the setting and ultra early strength of shotcrete. To regulate the setting and hardening of shotcrete, accelerators are commonly incorporated; however, the competition for calcium ions and the encapsulation of alite by ettringite hinder the coordination between rapid setting and ultra early high strength. This study investigates the synergistic effects of nano C-S-H seeds and accelerators, achieving segmented control over setting and hardening by adjusting the addition timing, and examines the impact of different addition times on the early compressive strength. The results showed that when nano C-S-H seeds are added one hour after the aluminum sulfate, the mortar's compressive strength can reach 2.21MPa in 6 hours. Through hydration heat, XRD, TG, SEM, BSE-EDS, mercury intrusion porosimeter, and ion concentration characterization, the mechanism of segmented control was revealed, clarifying the sources of ultra early strength in cementitious materials containing accelerators. The results demonstrate that nano C-S-H seeds significantly enhance the hydration of alite, and their delayed addition relative to accelerators can mitigate the competitive effect of calcium ions, inducing the C-S-H gel to fill the ettringite framework and achieving synergy between setting and early high strength. This study holds significant implications for resolving the contradiction between rapid setting and ultra early high strength in cementitious materials with accelerators, laying the groundwork for the development of efficient accelerators.

Keywords: Sprayed concrete; Accelerator; C-S-H nano-seeds; Ultra early strength; Working mechanism

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Deep learning approaches for prediction of adiabatic temperature rise of concrete with complex mixture constituents

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ABSTRACT

Temperature control and crack prevention of mass concrete are significant to the safety and durability of structures such as dams and long-span bridges. Adiabatic temperature rise is the key issue in thermal and crack risk analysis of mass concrete. Due to the substantial diversity of admixtures influencing the hydration process in modern concrete, it is challenging to develop a comprehensive analytical model to predict adiabatic temperature rise based on theoretical frameworks. As a data-driven approach, deep learning (DL) provides a potential solution for predicting properties of complex materials in recent years. DL model based on artificial neuron network (ANN) and recurrent neuron network (RNN) were employed in this study to forecast adiabatic temperature rise considering 15 variables as input parameters. The coefficient of determination (R^2) of results given from ANN and RNN were 0.7616 and 0.8542. Through k-fold cross validation, a DL model was developed for reliable prediction of adiabatic temperature rise of concrete with complex admixtures.

Keywords: Concrete, Adiabatic temperature rise, Deep learning, Recurrent neural network, Artificial neural network

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Early hydration analysis of siderite ($FeCO_3$)-cement systems

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ABSTRACT

Siderite ($FeCO_3$) from the Austrian Erzberg Mine has shown great prospects to be used as a supplementary cementitious material, with preliminary investigations portraying acceptable late strengths, accompanied by durability improvements in mortar samples. However, little is known of the early reactions of siderite in cementitious systems. To investigate this, OPC binder systems containing siderite powders with two different finenesses were characterized by pore solution analyses, isothermal calorimetry, and compressive strength testing. The results indicate that siderite retards the initial hydration of cement by hindering the dissolution of the clinker phases of cement, with finer powders exhibiting a stronger effect. Finer siderite-containing samples showed a higher iron concentration in the pore solutions at all studied times. Siderite-containing samples exhibited lower Ca^{2+} and SO_4^{2-} content in the pore solution than the quartz reference during the first 24 hours. This behaviour, which led to slower precipitations of Fe-AFm and C-S-H phases, was more pronounced in samples containing the finest siderite. The partially inhibited formation of C-S-H was confirmed by a 60% and 17% lower compressive strength in the siderite-containing mortars (fine and coarse, respectively) compared to the quartz sample. The slower hydration of siderite-containing mixes was also confirmed by isothermal calorimetry. The dissolution of siderite and the incorporation of iron in the solution are behind the slower dissolution of clinker phases and, consequently, lower values of early compressive strength; however, the exact mechanisms are yet to be understood.

Keywords: Siderite; Low-carbon cement; SCM; Pore solution

Power ultrasound assisted mixing cement-based material: mechanism, technology and application

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ABSTRACT

Power ultrasound (PUS) was first used to assist the mixing of cement paste. The compressive strength test was conducted. The hydration process and products of the cement paste were analyzed by inductively coupled plasma–optical emission spectrometry (ICP–OES), isothermal calorimetry, thermogravimetric analysis (TGA), quantitative X-ray diffraction (QXRD), mercury intrusion porosimetry (MIP), backscattered electron–energy dispersive spectroscopy (BSE–EDS), environmental scanning electron microscopy (ESEM). The results indicated that the compressive strength was improved by using the PUS-assisted mixing. Moreover, PUS-assisted mixing significantly promoted the formation of calcium hydroxide (CH) and ettringite. The crystallization and densification process of the C-S-H phase was accelerated. The macroscopic voids and large capillary pores were substantially reduced. Additionally, applying PUS-assisted mixing decreased the average equivalent diameter of graphene oxide agglomerates in cement paste. Therefore, PUS-assisted mixing is a promising technology for improving hydration behaviours and strength of cement paste, which could be used in fabricated production.

Keywords: Power ultrasound assisted mixing; Hydration; Microstructure; Dispersion

A designed polymer-based lunar regolith concrete for versatile construction on the lunar surface

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ABSTRACT

Lunar base construction plays a crucial role in lunar resource exploitation. However, the harsh lunar conditions and high transportation costs between Earth and the Moon present challenges for lunar construction. Developing lunar construction materials that are practical for versatile scenarios while maximizing in-situ utilization is a formidable task. In this study, we report a designed polymer based lunar regolith concrete (PLC) and develop various approaches for different lunar application scenarios by combining direct extrusion 3D printing and pressing processes. On the one hand, the flowable PLC enables the fabrication of complex elements using extrusion 3D printing, resulting in exceptional mechanical strength and interlayer bonding strength. Additionally, high-utilization PLC bricks prepared through the pressing process maintain enough load bearing strength. Notably, the PLC retains good mechanical performance after being exposed to harsh environments such as extreme temperature fluctuations, high vacuum, highlighting the outstanding stability of PLC in lunar environments. Consequently, this specially designed PLC emerges as an ideal candidate for lunar construction under extreme conditions.

Keywords: Lunar construction; Polymer lunar concrete; 3D printing; Pressing

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A new insight into the effect of CO_2 curing on subsequent hydration of cementitious materials

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ABSTRACT

The use of a variety of technological methods for quantitative characterization allows for the correlation of hydration reaction kinetics, carbonation product micromorphology and the effect on subsequent hydration after CO_2 curing. CO_2 curing exhibits an advancement of the second exothermic peak of the hydration reaction by 5-6 hours in comparison to the 3.5-4.5 hours advance in the hydration group. This can be attributed to the strong under-saturation of ions in the suspension after dissolving CO_2, as well as the nucleation sites provided by the carbonation products, such as nano-calcium carbonate, silica gel or/and alumina gel. CO_2 curing the cementitious materials at a high W/C would not detrimentally affect the subsequent hydration, but instead promote it as evident from quantitative analyses of ICC, QXRD, NMR and SEM. The formation of misty silica gel or silica gel with a small amount of alumina gel after CO_2 curing is primarily distributed on the outside of the clinker particles, poorly connecting with the matrix.

Keywords: CO_2 curing; Carbonation products; Subsequent hydration; Cementitious materials; High W/C

Exploring reactivity parameters of Fe-rich slag in alkali-activated materials

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ABSTRACT

The potential of Fe-rich non-ferrous metallurgical slag (NFS) in alkali-activated materials has been demonstrated, showing promising mechanical strength and fire resistance. However, the variability in NFS chemical composition, primarily Fe and Si, poses challenges to its reactivity and consequently affects properties such as strength and durability of alkali-activated NFS (AA-NFS). This study aims to explore the parameters influencing the reactivity of predominantly amorphous phase slag in FeO-SiO_2-Al_2O_3-CaO-(MgO) glass. The examined parameters include basicity, optical basicity, NBO/T ratio, metal-oxygen bond energy (suggested for CaO-MgO-Al_2O_3-SiO_2 glasses), and K-value, known to correlate with Fe-rich slag. Five variants of NFS with distinct chemistries were investigated. Slag reactivity was assessed in terms of reaction extent and kinetics. Backscattered Electron-Image Analysis (BSE-IA) evaluated reaction extent, while isothermal calorimetry analysis assessed reaction kinetics. Results indicate a strong correlation between reaction kinetics and basicity/optical basicity, and a stronger correlation between reaction extent and average energy bond in the slag. This study provides valuable insights into the reactivity of Fe-rich slag, facilitating its application in cementitious materials.

Keywords: Fe-rich slag; Alkali-activated materials; Slag reactivity; Strength
c

Experimental investigation of low-carbon concrete using biochar as partial cement replacement

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ABSTRACT

Cement is the main constituent of concrete and the primary contributor to CO_2 emissions. An experimental study was carried out to examine low-carbon concrete using biochar as a partial cement replacement. Materials characterisation methods, such as sieve analysis of biochar, sand and coarse aggregates, water absorption, density, initial and final setting times, workability, and compressive strength were employed. The resultant theoretical embodied carbon of concrete was also calculated to establish the reduction in carbon emissions due to the use of biochar as partial cement replacement. Various replacement amounts were considered, namely, 5%, 15%, 30%, 45% and 60% replacement of CEM I with biochar by weight. The experimental results showed that biochar has high water absorption capacity and low specific gravity. With the increasing replacement percentage of biochar, the initial and final setting times were decreased. The compressive strength was also decreased, but this was less pronounced for the lower replacement levels, such as 5%. The main advantage of using biochar was the reduction in the embodied carbon. It was found that as biochar is a low-carbon material, it will result in a reduction of the embodied carbon of concrete. With higher replacement values (of 30%~60%), although the compressive strength is reduced significantly, there is potential for use in low-strength concrete applications such as bricks and blocks and for non-structural applications.

Keywords: Biochar; Low-carbon concrete; Carbon sequestering; Concrete structures; Compressive strength; Embodied carbon

STUDENT COMPETITION
(Session SC-A2)

Preparation technology and carbon footprint evaluation method for coral aggregate seawater concrete

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ABSTRACT

The preparation of Coral aggregate seawater concrete (CASC) by using coral reef and coral sand as coarse and fine aggregates and seawater mixing and curing is of great strategic significance and economic value in the construction of islands and reefs in China. In this paper, Portland cement used for island project was studied, which was prepared with active mixture materials such as Portland cement clinker, gypsum, coral powder, ground slag or fly ash. The effect of coral particle size distribution on the compressive strength of the cement-coral powder system is analysed, drawing on data from relevant tests. Additionally, foundational application technologies of reef cement within CASC are examined, employing methods such as isothermal calorimetry, X-ray diffraction (XRD), thermogravimetric analysis (TG), scanning electron microscopy (SEM), and backscattered electron (BSE) imaging. Coral powder and aggregates, sourced locally, are utilized in the reef cement, while cement clinker, gypsum, and admixtures are transported to the site by ship, and all necessary materials for conventional Portland cement concrete are brought from the mainland. Through analysis of the concrete mix ratio, the total carbon emissions associated with the production and transportation of both standard Portland cement concrete and comprehensive coral concrete are meticulously quantified, leading to an extensive carbon footprint assessment.

Keywords: Coral aggregate seawater concrete; Portland cement; Carbon footprint evaluation; Sustainable construction materials; Compressive strength
c

Development of low-carbon ultra-high performance concrete with low cement content: workability, mechanical properties, and microstructure characterization

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ABSTRACT

To reduce the carbon footprint, a tailored low-carbon ultra-high performance concrete (LC-UHPC) with low cement content (30%) was developed in this study at room temperature, in which the dual roles of cement acted as the binder and the alkaline activator to the slag were exploited. To evaluate its practical applicability, systematic investigations on the workability, mechanical properties, microstructure, hydration products, and environmental impact of the proposed LC-UHPC were conducted. The results showed that the substitution of cement with slag at a large proportion will induce notable modifications in the microstructures and phase compositions of LC-UHPC, leading to the alteration in the macroscopic mechanical responses. Compared with OPC-UHPC, LC-UHPC with only 30% cement content possessed superior mechanical performance that exhibits comparable ultimate compressive strength and peak strain, while a significant improvement in toughness by 58%. Moreover, in comparison with the fiber-free specimen, the ultimate compressive strength and toughness of LC-UHPC containing 2.0% steel fiber content were further improved by 1.12 times and 31.17 times, respectively. At last, upon the analyses using thermodynamic modeling, it is revealed that 30% cement content in the binder is sufficient to activate the hydration activity of slag and generate a significant amount of densely packed hydration products at the microstructural level. This capability enables LC-UHPC to achieve a substantial reduction in cement content and carbon emission without compromising the mechanical performance, providing a new routine for the development of LC-UHPC.

Keywords: LC-UHPC; Cement replacement ratio; Mechanical performance; Microstructural alteration; Carbon footprint

Multi-scale microstructure quantitative characterization and anti-erosion performance of PHC pipe pile

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ABSTRACT

Pre-stressed high-strength concrete (PHC) pipe pile is widely used in many large-scale projects, thus their durability has attracted more and more attention. However, in most studies, PHC pipe pile is regarded as the same as ordinary reinforced concrete, ignoring the effect of special construction processes and hollow shape on its microstructure and anti-erosion performance. In this paper, the real PHC pipe pile was cored and cut to investigate the multi-scale microstructure and the anti-erosion performance of PHC pipe pile concrete layer. The results shown that pore content first increases and then decreases with PHC pipe pile from the outer layer to the inner layer (5F → 1F) by CT, BSE and LF-NMR results, and the pore content changes most significantly around the rebar in PHC pipe pile. In rebar interfacial transition zone (ITZ), the thickness of the voids in PHC pipe pile is greater than that of normal reinforced concrete under the same water-binder ratio condition. Additionally, the content of un-hydration products in aggregate ITZ is obviously greater than that in rebar ITZ. Furthermore, the chloride ion diffusion coefficient of the concrete on the outside of the PHC pipe pile is slightly larger than that on the inside, which is closely related to the higher pore connectivity of the concrete on the outside of the PHC pipe pile. Moreover, it was found that centrifugation can not only reduce the water-binder ratio of PHC pipe pile but also affect the radial pore structure of PHC pipe pile concrete, including porosity and pore connectivity. This work finally indicated that the microstructure of PHC pipe pile concrete is quite different from that of normal reinforced concrete, providing a theoretical basis for establishing the diffusion model of PHC pipe pile concrete.

Keywords: PHC pipe pile; Centrifugation; Multi-scale characterization; Interfacial transition zone; Anti-erosion performance

c

Ex-situ carbon mineralization product as an alternative supplementary cementitious material: experimental and gems modelling investigation

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ABSTRACT

The last IPCC report shows evidence that the temperature rise will reach or exceed 1.5 °C between 2021 and 2040 with a probability between 40% and 60%; hence, technologies for CO_2 sequestration are urgently needed. Since ordinary Portland cement production contributes to the increase of CO_2 in the atmosphere, it is recommended to replace cement with supplementary cementitious materials with a lower or negative carbon footprint. The aim of this study is to evaluate ex-situ carbon mineralization product (e.g., carbonated olivine) as a new supplementary cementitious material. Using carbon mineralization product as cementitious material has a double advantage in reducing carbon footprint of binding material. The carbon dioxide captured through carbon mineralization is in addition to that avoided through cement replacement. The new binder formulation encompasses a 20 / 30 wt% replacement of Portland cement with carbonated olivine, which is mainly composed of magnesite and amorphous silica. The early age and long-term reactivity of the new binder were monitored by in-situ X-ray diffraction measurements (early 24 hours) and ex-situ measurements (7, 28 and 90 days of ageing time). The experimental results were compared with thermodynamic modelling outputs as obtained by GEMS. The amorphous silica in carbonated olivine has pozzolanic activity, whereas magnesite remains stable under alkaline conditions. The transformation of magnesite and portlandite into calcite and brucite by alkaline-magnesite-reaction as predicted by thermodynamic modelling is prevented by the kinetics of reactions occurring during the hydration of the binder.

Keywords: *Ex-situ* carbon mineralization, Alternative supplementary cementitious material, GEMS, Cement hydration

Developing green environmental protection concrete for engineered material arresting system

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ABSTRACT

The out of control of the aircraft is very dangerous to people's lives. The overrun of the runway is mainly due to human errors, the loss of control in wheel alignment, the speed of the approach is too fast, and the landing time is too long. The Engineered Materials Arresting System (EMAS) is used to prevent the aircraft from rushing out of the runway before the aircraft enters the hazardous terrain. In order to maximize the hazards of overrun, in order to maximize the hazards of over -loading capacity, the U.S. Federal Aviation Administration (FAA) stipulates to maximize the hazards of overrun. The Royal Airlines uses physical similarity and outline analysis technology to evaluate the effectiveness of the gravel layer, and accurately predicts the distance required to stop the aircraft at a given speed. Blocking beds can be made in different materials. Due to its excellent energy absorption characteristics, foam concrete (FC) has been used in the airport runway engineering material blocking system. Foam concrete is made of foam in the cement through the principle of chemical or physical principles to make a foam through a foaming solution of the foaming agent, so that the concrete inside the concrete has a large number of closed pores green light concrete. Strong, despite the low density. The composition of FC mainly includes water, cement, air bubbles, etc. It can be processed by various mixes, which can use a large amount of industrial waste residue as raw materials, replace the amount of cement according to a certain proportion, reduce carbon emissions, and reuse construction waste. It can not only reduce the cost of engineering cost, but also meet the national sustainable development strategies and green development requirements.

Keywords: Engineered materials arresting system; Runway end safety area; Runway overrun; Green environmental protection concrete; Foam concrete
c

New method for concrete carbon emission evaluation: the durability-oriented carbon emission indicator (CEI) system

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ABSTRACT

This study proposes a novel carbon emission evaluation index system for cement-based composite materials, oriented towards freeze-thaw durability. This system comprehensively considers the lifecycle emissions of materials, with a particular focus on the impact of concrete durability on carbon emissions. By integrating assessments of carbon emissions per unit strength, per unit freeze-thaw lifespan, and per unit (strength*lifespan), it effectively promotes the design and development of low-carbon, high-performance concrete. This innovative approach not only helps reduce carbon emissions during concrete production and use but also enhances concrete durability, thereby driving the construction industry towards a more environmentally friendly and sustainable direction.

Keywords: Low-carbon Cement Concrete, Carbon Emission Evaluation Indicators, Durability, Systematic analysis, Mix Proportion Design

STUDENT COMPETITION
(Session SC-B2)

Effect of nanoparticles and surfactants on properties and microstructures of foam and foamed concrete

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ABSTRACT

The stability of foam is an important factor affecting the stability and strength of foamed concrete. In this study, the foams were prepared by coupling the effects of nanoparticles and surfactants. Multiple methods were employed to investigate the properties and microstructures of various foams and their impacts on properties of foamed concrete. Results reveal that the addition of nanoparticles increased the foam density while decreased the foaming multiplicity, water secretion rate and settling distance, irrespective of surfactant types. Nanoparticles can be combined with the groups of surfactants by electrostatic force, which limits the gas-liquid contact area and the coarsening of bubble and thus stabilizes the foams. Generally, nano-silica (NS) stabilized the foams better than nano-calcium carbonate (NC). Nanoparticle-modified foams reduced the fluidity and increased the viscosity of foamed concrete, and owing to the more irregular and rougher surface, NC had more noticeable effect on fluidity and viscosity than NS. Nanoparticles can change the Ca/Si ratio of pore wall of the foamed concrete and affect the cement hydration, therefore enhancing the strength of foamed concrete to some extent.

Keywords: Foamed concrete; Nanoparticles; Surfactants; Stabilized foam; Microstructure
c

Calcium formate or calcium chloride as an accelerator in cementless slag based UHPC: hydration mechanism printing

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ABSTRACT

The increasing CO_2 emissions from cement production necessitate the exploration of alternative materials to replace ordinary Portland cement. In this study, a CaO-activated GGBFS-based Ultra-High-Performance Concrete (UHPC) is investigated. However, the early strength of this system is relatively lower. To address this issue, calcium formate and calcium chloride are employed as accelerators. The study aims to compare the mechanical and microstructural properties of UHPCs using different accelerators and determine the most effective one. Calcium formate produces a higher compressive strength UHPC compared to calcium chloride. The CaO-activated GGBFS UHPC with calcium formate as an accelerator exhibits more hydration products, as evidenced by NMR. The micro pores of the UHPC are denser when using calcium formate as an accelerator, compared to calcium chloride as per MIP analysis. This research contributes to the understanding of alternative cementitious materials and their potential to reduce CO_2 emissions in concrete production.

Keywords: CO_2 emissions; Accelerator; Calcium formate; Calcium chloride; Micro pores

Effects of nano additives and carbonates on hydration of silicate and aluminate phases in low-carbon cement

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ABSTRACT

In the cement industry, the use of supplementary cementitious materials (SCMs) offers a significant potential to reduce carbon emissions and to conserve precious natural resources. However, in light of the increasing demand for cleaner fuels in power plants, the supply of traditional SCMs such as GGBS and FA is expected to decrease significantly soon. Thus, it is important to investigate the availability of alternative low-carbon SCM materials such as calcined clay. This study investigated the influence of different carbonates (limestone, magnesite, various hydrated magnesium carbonates (HMCs), and amino acid-modified HMCs) and non-carbonate (quartz) sources on the performance of Portland metakaolin cement binders. The mixtures show a distinct difference in strength at early ages (i.e. 3 to 7 days), while at later ages (i.e. after 28 days) compressive strengths were similar for all the binders. Also, the microstructure was densified by the amino acid-modified HMCs. The synergistic reaction between metakaolin and high-reactivity carbonate produces carboaluminates, which may explain the increase in strength. Moreover, the strength gain cannot only be attributed to carboaluminates, other hydration products also play an important role (e.g. stratlingite and C-A-S-H gel). The effects of colloidal nanosilica (CNS) on the hydration and hardening properties of Limestone Calcined Clay Cement (LC^3) were also investigated. The effects of CNS on hydration reaction, fluidity, mechanical properties and microstructure of LC^3 were then investigated. According to the results obtained from isothermal calorimetry and thermogravimetric analysis, CNS can considerably accelerate the reaction rate of the LC^3 system. 3% and 5% by weight CNS can significantly improve the compressive strength of LC^3 blends, especially at early ages up to 7 days. The findings from this study lead to a better understanding of the modification effects of CNS on LC^3, which subsequently provides insight into the regulation mechanism of CNS on LC^3.

Keywords: Limestone calcined clay cement (LC^3); Colloidal nano SiO_2; Carbonates
c

Optimizing concrete performance through the integration of stone dust powder: an eco-friendly perspective

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ABSTRACT

The disposal of stone dust powder (SDP), a byproduct of stone-crushing processes, having a particle size finer than 75µm poses environmental challenges, impacting ecosystems, societies, and human well-being. In this study, we investigate the eco-friendly application of SDP in concrete production, exploring its potential to enhance mechanical properties and durability while mitigating the adverse effects of waste disposal. A series of designs for concrete mixes were developed that included SDP as the 4th aggregate. River sand is directly replaced by the SDP up to 400 kg/m^3 in different sets of mix. Results show that adding up to 300 kg/m^3 significantly improves mechanical characteristics such as compressive and split tensile strength. Furthermore, up to 400 kg/m^3 of SDP replacement, durability attributes such as RCPT, permeability, and water penetration continue to improve. According to microstructural studies, the "filling" and "nucleation" actions improve the overall qualities of the concrete. However, more than 400 kg/m^3 of stone dust powder (SDP) in concrete adversely affects fresh properties, increasing total admixture demand and impacting mix cohesiveness. Elevated SDP content demands more admixtures, potentially causing economic concerns in large-scale applications. Also, the excess powder affects water demand, necessitating mix design adjustments for optimal consistency. Balancing SDP addition is crucial to prevent detrimental effects on workability and cohesiveness during construction. In addition to offering a practical and effective disposal route for SDP and other non-pozzolanic industrial waste materials, this study promotes an enhanced allowable value of SDP content in concrete applications. The suggested method is in line with sustainability principles and offers a sustainable and practical way to lessen the damaging effects that waste products have on the environment and public health.

Keywords: Stone dust powder, Fillers, Sustainable development, Non-pozzolanic industrial waste

Low-emission supersulfated cement modified by steel slag: hydration, mechanical properties and life cycle assessment

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ABSTRACT

Facing increasing pressure to reduce carbon dioxide emissions, Supersulfated cement (SSC), which requires only a minimal amount of cement clinker (<5%), has attracted more attention due to its remarkably low CO_2 emissions. This study attempts to incorporate low-carbon emitting steel slag (Basic Oxygen Furnace Slag, BOFS) into SSC to prepare a BOFS modified supersulfated cement (BMSC) with even lower CO_2 emissions. We systematically investigated the performance of BMSC using methods such as QXRD and life cycle assessment evaluation of the materials used. The results indicate that the inclusion of 10% BOFS can enhance the 7-day and 28-day strength of BMSC. BOFS positively influences the formation of ettringite, and the C_2S and C_4AF within BOFS demonstrate distinct hydration activity. The results of the LCA evaluation show that the replacement of GGBS with BOFS can reduce CO_2 emissions associated with SSC by over 30%.

Keywords: Supersulfated cement; Low emissions cements; Steel slag; Hydration mechanism; Microstructure

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Roman concrete-inspired hydraulic cementitious composites for artificial reef engineering

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ABSTRACT

Natural reefs not only provide habitats for marine species, but also play a vital role in carbon capture and storage. However, in recent years, thermal stresses from global warming and increased water acidification from CO_2 absorption have contributed massively to natural reef degradation through coral bleaching and by decreasing the ability of several marine species to build calcium carbonate ($CaCO_3$) shells. Artificial Reefs (ARs) can address many of these issues in coastal zones by performing functions similar to natural reefs, such as providing shelter and nutrients for marine organisms. Furthermore, ARs made of limestone and sustainable binders can help mitigate the effects of global warming and contribute to the revitalization of ailing coral reefs through absorbing and storing dissolved CO_2 in the ocean.

In this research, materials for ARs are synthesized using novel archaeologically inspired composites. Novel cementitious materials modeled on ancient Roman marine concrete were produced by mixing slaked lime ($Ca(OH)_2$) with recycled industrial and biological waste. Mortar composites prepared with slaked lime, supplementary cementitious materials (SCMs), and aggregate produce a smaller carbon footprint when compared to Portland cement. This reduction is due to the partial volume replacement by SCMs and the lower energy required to produce calcined limestone. Natural seagrass fibers (*Posidonia Oceanica*), quicklime (CaO), and calcium sulfate hemihydrate ($CaSO_4 \cdot 0.5H_2O$) powder were added to samples to improve toughness and hardening rates. Samples were mixed with natural and artificial seawater to test its effects on the properties of the resulting mortars. The synthesized materials were tested and evaluated based on their microstructural, chemical, and mechanical properties. Materials characterization was performed using SEM-EDS and Powder XRD. Mechanical properties of the materials were evaluated using compressive strength testing according to ASTM C109 standards.

Keywords: Roman concrete, Waste materials, Natural fibers, Fly ash, Mechanical properties

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STUDENT COMPETITION
(Session SC-A3)

Scalable and durable radiative cooling cement via metasurfaces engineering

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ABSTRACT

Passive daytime radiative cooling (PDRC) rises as an energy-free strategy for heat transfer and space cooling by simultaneously reflecting sunlight (0.25 to 2.5 μm) and emitting infrared radiation (8 to 13 μm) to the cold universe (~3 Kelvin), which is promising to cut down the dependence on air conditioners and thus reduce carbon emission. It remains a substantial challenge to fabricate scalable, high-strength and durable low-carbon radiative cooling structural materials through the whole life cycle while satisfying the need of low-cost, plasticity and structural integrity in civil engineering. Herein, we first exploited white sulphoaluminate cement with high radiative cooling properties including reflectance and emissivity, and engineered the surface of cement composites to further enhance the cooling performance. This pressure difference-driven strategy could generate concaved microcavities which are periodically distributed on the surface with rod-like and randomly distributed hydration products ettringite crystals assembling inside as scattering elements for higher reflectance. Our cement composites exhibit high solar reflectance (96.2%) and intrinsic mid-infrared emissivity (96.0%), and achieve a temperature drop of 5℃ and 7℃ at midday and nighttime respectively under a solar intensity of 800 W/m^2, exhibiting global energy-saving potential. High mechanical robustness, environmental durability and aesthetic designability guarantee the versatile functionalities when applied to the building envelopes under various hazardous environments.

Keywords: Radiative cooling; Cement; Metasurface; Building; Carbon neutrality

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Carbonation of fly ash concrete exposed to high temperature

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ABSTRACT

Cement production is one of the major reasons for CO_2 emission contributing about 8% globally. To counter this, many new and innovative methods are being used since long time like using waste materials as an alternative binder or as an aggregate replacement in concrete. In this study, Class F fly ash is used as an effective binder replacement and mix designs are based on the K-factor theory. This theory is based on the concept of equivalent 28 days strength. Previous studies have shown positive results in mechanical as well as durability aspect, however carbonation behaviour have shown the opposite trend in case of fly ash-based concrete. Carbonation is one of the major durability issues which can lead to corrosion of embedded steel bars, one of the major reasons of deterioration of concrete structure. Also, one of the hazard types that affect building constructions frequently is fire. Severe fire can compromise the long-term service safety of concrete by reducing its mechanical properties, including its elastic modulus, tensile strength, flexure strength and the durability properties like gas permeability, water absorption, carbonation resistance, and chloride diffusion coefficient. Nevertheless, there are inadequacies in the studies on the resilience of fire-damaged concrete, particularly with regard to its degradation and assessment of its carbonation resistance. This study, in particular, focuses on the carbonation resistance of fly ash - concrete exposed to normal as well as elevated temperatures. A fixed w/b of 0.5 was considered with 0, 15% and 30% effective replacement of cement with fly ash. Compressive strength was tested after 7 and 28 days of curing resulting in the approximately equal strength of 26Mpa and 33MPa respectively.

Keywords: Carbonation; Elevated temperature; Fly ash, K-factor

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Study on the performance and carbon emission analysis of magnesium phosphate cement mortar

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ABSTRACT

To investigate the impact of different mineral powders on the properties of Magnesium Phosphate Cement (MPC) mortar, this study designed MPC mortar and MPC paste with various mineral powders to evaluate the performance of MPC in repairing different types of defects such as cracks and surface spalling in airport concrete pavements. The test results of flexural bond strength, splitting tensile bond strength, surface pull-off strength, and fracture toughness indicate that, under the same MPC mix ratio, the incorporation of fly ash and slag can extend the setting time of MPC mortar but lead to a decrease in mechanical properties. Additionally, this study also explored the effectiveness of producing MPC mortar with calcined magnesium oxide and fly ash in reducing carbon emissions during the production phase and compared it with traditional Portland cement mortar. The findings reveal that producing MPC paste and MPC mortar using calcined magnesium oxide and mineral powders can significantly reduce carbon emissions. Specifically, the carbon emissions of MPC paste prepared with magnesium oxide and mineral powders were reduced by 38.95% compared to those prepared with only magnesium oxide without mineral powders. However, this still represents a 27.67% increase in emissions compared to traditional Portland cement mortar. Compared to MPC mortar prepared with only magnesium oxide without mineral powders, the carbon emissions of MPC mortar prepared with both magnesium oxide and mineral powders were reduced by 19.33%, which is a 24.91% reduction in emissions compared to traditional Portland cement mortar.

Keywords: Magnesium; Phosphate mortar; Mechanical properties; Fly ash; Carbon emission

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Electrocatalytic reduction of CO_2 and its effect on the properties of cement-based materials

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ABSTRACT

Carbon dioxide (CO_2) from rotary kiln is one of the main sources of carbon emission, and thus converting CO_2 from cement industry into valuable products is an effective means to reduce carbon emission. At present, there are few studies on the application of catalytic reduction products of CO_2 to cement-based materials. In this study, a highly stable three-dimensional Cu_2O/Cu catalyst was prepared by electrodeposition on carbon paper, which efficiently reduced CO_2 to formate in $KHCO_3$ electrolyte containing cetyltrimethylammonium bromide (CTAB). The effects of the mixed electrolyte products on the properties of cement-based materials were further investigated. The results showed that the mixed solution of electrolyte and catalytic products could shorten the setting time and improve the early strength. The direct use of CO_2 catalytic reduction products in cement-based materials can reduce the cost of product separation, which is one of the research directions of “carbon reduction and carbon utilization” in the future.

Keywords: Electrocatalytic reduction CO_2, 3D structure, Faraday efficiency, Cement, Compress strength

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Utilising low Al/Si materials manufacturing ternesite - ye'elimite cement and its long-age performance

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ABSTRACT

Ternesite-ye'elimite cement (TYC) is a new type of low-carbon cement with low calcination temperature, less CO_2 emission and excellent performance, but its raw materials still rely on high-grade bauxite. In order to expand the selection range of TYC raw materials, the effect of different calcination conditions on the firing of TYC clinker that prepared different amounts raw materials of low Al/Si ratio was investigated by designing four groups of TYC clinker with different ternesite contents. The influence of ternesite content on the long-age physical and mechanical properties was studied and hydration process of the cement was analysed via microscopic tests of hydration products. The results of the study show that TYC clinker with low Al/Si ratio raw materials was best prepared when mineralizers were added and the calcination temperature was 1150 °C. The morphology of TYC clinker had different sizes, close packing degrees and overall porosity caused by different ternesite contents, which had certain effects on the cement hydration. The increase of ternesite content prolonged the setting time of TYC, more importantly, led to a steady and sustainable growth of the pH value and compressive strength of the hardened cement pastes after 28 d. In short, it is feasible to prepare TYC from raw materials with low Al/Si ratio.

Keywords: Ternesite-ye'elimite cement; Low Al/Si material; Ternesite content; Long-age performance

Properties and hydration characteristics of an iron-rich sulfoaluminate cementitious material under cold temperatures

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ABSTRACT

Cold environment poses a significant challenge to the construction industry, underscoring the importance of developing low-temperature cementitious materials. This study svnthesized iron-rich calcium sulfoaluminate (IR-CSA) cement from industrial waste slag and assessed its performance and hydration characteristics under various curing conditions: constant temperaturesof5 'C, 0 'C, -5 'C, and -10 'C, as well as variable negative-temperature conditions. Results showed that the addition of Fe20:altered the minerals" reaction pathways and clinker composition, promoting a transition from orthorhombic to cubic crystal structure. This modification enhanced the exothermic properties of hydration and improved frost resistance compared to ordinary calcium sulfoaluminate cement. Despite a slight decrease in early compressive strength with decreasing curing temperatures, IR-CSA maintained significantly higher strength than Pc. Lower temperatures (0-5 °C) hindered the initial formation rate of AFt and resulted in fewer harmful pores due to appropriate early hydration rates. Conversely, negative temperatures caused water in the paste to freeze, retaining unhydrated phases and increasing harmful pores. Variable negative-temperature curing regimes closely followed ambient temperatures, leading to increased formation of large pores and microcracks compared to constant temperature curing. Overall. the study demonstrates the feasibility of applying solid waste-based IR-CSA clinker in cold region construction projects.

Keywords: Sulfoaluminate cement; Steel slag; Cold temperature; Compressive strength; Hydration mechanism

Carbonation process of ternesite: properties, product evolution and reaction mechanism

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ABSTRACT

In this study, ternesite was proposed as a low-lime CO_2 sequestration binder, and the ternesite slurry and compacts were carbonated in different periods. The evolution of ternesite carbonation products and properties was studied by qualitative and quantitative analysis, and the kinetics equation of ternesite carbonation was established. According to the microstructure, crystasize and phase composition of carbonated products, a conceptual model of the carbonation hardening process mechanism of ternesite was constructed. The results showed that ternesite CO_2, sequestration capacity and compressive strength of ternesite reached 15.19% and 91.95 MPa after carbonation for 120 min. Ternesite has been shown to quickly obtain a hardened product with good properties through carbonation curing, opening up the field of CO_2 sequestration binder.

Keywords: Ternesite; Carbonation; Compressive strength; CO_2 sequestration binder; Low-carbon cement

STUDENT COMPETITION
(Session SC-B3)

Enhancement of mechanical and durability properties of alnminum powdered expanded grout by limestone powder and sulfates

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ABSTRACT

Cement grouting materials incorporating aluminum powder can enhance the extrusion of the matrix to the anchor and enhance the bonding of them, but the mechanical properties will be greatly reduced. In this study, the effect of fly ash blended cements on physical and mechanical properties and durability were investigated through such tests as compressive strength, self-shrinkage strain, chloride ion diffusion coefficient, capillary water absorption by mixing limestone powder with sulfate on the basis of guaranteeing the expansion of the grout. The results were showed that 4% limestone powder has improved the compressive strength at all ages, and both 1.5% gypsum dihydrate and 0.8% sodium sulfate could play a synergistic role with limestone powder to improve the early strength, and exhibits lower chloride ion diffusion coefficient and lower capillary water absorption. This was due to the addition of sulfate, which together with carbonate promoted the deposition of more stable carbon-aluminate and many other phases. This facilitated the refinement of the pore space, which improved their mechanical and durability. Significance: In this study, mineral admixtures synergistic activator are used to effectively improve the performance of aluminum powder expansion grouting materials and will have a high practical application value in low carbon development and engineering.

Keywords: Grouting materials; Aluminum powder; Sulfate; Limestone powder; Expansion performances

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Service life prediction of marine reinforced concrete considering the effect of oxygen

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ABSTRACT

Chloride-induced corrosion of steel bars is the main cause for performance deterioration of marine reinforced concrete (RC), which poses severe threats to the security and service life of RC structures. Meanwhile, oxygen is a crucial factor affecting the corrosion of steel bars under a high chloride environment. However, the effect of oxygen is not adequately considered in existing life prediction models. In this work, the oxygen diffusion in concrete and the effect of oxygen concentration on the steel bar passivation, de-passivation, corrosion propagation, and concrete cracking was investigated. Meanwhile, a new service life prediction model was developed considering the effect of oxygen for the whole process of corrosion and used to predict the service life of Jiaozhou Bay Bridge in Qingdao, China. The results show that the oxygen diffusion coefficient of concrete was decreased with its internal relative humidity (RH) and water-binder ratio increasing. The passivation of steel bars is accelerated about 40 h and the critical chloride ion concentration is decreased by 21% when the dissolved oxygen content is increased from 2 mg/L to 6 mg/L. In addition, the corrosion of steel bars is inhibited with the oxygen insufficiently supplying, resulting in the steel bar will be repassivated. In contrast, the corrosion of steel bars is propagated with the sufficient oxygen supply. Moreover, the crack time of reinforced concrete is advanced about 130 h when the oxygen concentration is increased from 5% to 85%. The service life of RC structures is divided to two periods of induction and development and its prediction model is established based on the model of DuraCrete and non-uniform corrosion. Meanwhile, the effect of oxygen for the whole process of corrosion is considered in the established prediction model.

Keywords: Oxygen diffusion; Reinforced concrete; Steel bar corrosion; Service life prediction; Chloride ions

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Thermal stability of low-carbon cements formulated with brick powders of different reactivities

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ABSTRACT

Numerous studies have demonstrated that calcined clay can effectively replace traditional supplementary cementitious materials (SCMs) in the production of low-carbon cement. The raw material for bricks is also clay. Whilst calcined clay is typically produced at temperature below 850°C, brick, with its raw material also being clay, is usually fired at around 1000°C. However, excessively high temperatures may cause recrystallization of clay minerals, leading to loss of the pozzolanic reactivity of clay. Nonetheless, due to the higher thermal history experienced by brick as compared to calcined clay, brick powder (BP) blended cement may potentially possess better thermal stability.

The aim of this research is, therefore, to investigate the effects of substitution of Portland cement with BP in cement paste on the thermal stability of hardened blends. Two types of BP with different reactivities, namely KD (higher reactivity) and BU (lower reactivity), along with a commercial metakaolin (MK) which was used as control, were investigated. The blended hardened cement pastes were examined after exposure to different elevated temperatures (50, 200, 400, 600, 800, 1000°C). The physical properties, including compressive strength, mass changes, and volume changes, were evaluated. The phase evolution of cements was analysed by thermogravimetric analysis, infrared spectroscopy, X-ray diffraction.

The results demonstrated that the compressive strength reduction rate of KD and BU after 400°C was greater than that of MK. This may be due to the lower reactivity of BP compared to MK, resulting in the presence of higher content of calcium hydroxide (CH) in the BP blended cement. In addition, the volume stability of BP blended cement was superior to that of MK. At 800°C, the volume shrinkage of MK blended cement is approximately twice that of BP blended cement. This difference may be attributed to the lower reactivities of BP, which results in the formation of less amount of C-(A)-S-H in BP blended cement. Upon exposure to 800°C, the decomposition of C-(A)-S-H into calcium silicate may leads to significant volume shrinkage. In conclusion, when BP is used as SCM, shows better volumetric stability at high temperatures compared to MK blended cement, which could partly be attributed to the higher temperature compared to MK blended cement. On the other hand, the lower reactivity of BP leads to less contents of C-(A)-S-H and CH being formed in the cement matrix. The lower amount of C-(A)-S-H may result in less mass loss and volumetric shrinkage of BP blends at 200°C and 800°C, while a lower amount of CH may lead to a less strength decrease after 400°C.

Keywords: Brick powder, calcined clay, low-carbon cement, SCMs, thermal stability

Expanded titanium-bearing blast furnace slag phase change aggregate: preparation, performance and phase change energy storage mortar application

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ABSTRACT

Expanded titanium-bearing blast furnace slag (ETS), containing rich connected pores, largely accumulated and urgently consumed, due to low hydration activity and particle strength. In this study, the pore system of ETS was fully utilized to load paraffin for fabrication of phase change aggregate (PCA), and then the PCA was used to prepare phase change energy storage mortar (PCEM) and mechanical properties, thermal performances and energy-saving efficiency were subsequently evaluated. The results indicated that PCA has a paraffin loading rate of 21.9%, latent heat of 65.7 J/g for melting and 65.0 J/g for freezing, and good chemical compatibility. The 28-day and 56-day compressive strength of mortar containing 100% PCA reached to 7.8 MPa and 8.6 MPa. The energy saving efficiency of building reached to 8.1%, the peak indoor temperature of building decreased by 1.2 °C and 2.3 °C in spring and summer, respectively. These facts give confidence of ETS consumption in building energy-saving materials.

Keywords: Titanium-bearing blast furnace slag; Phase change aggregate; Phase energy storage mortar; Energy-saving ability

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Preliminary study on carbonation of recycled concrete slurry waste from ready-mix concrete plant for substituting cement

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ABSTRACT

The reduced early-age properties of cementitious materials substituted recycled concrete slurry waste (RCSW) hinder its utilisation, which can be further improved via early-age carbonation curing by sequestering the CO_2. This study, is thus, aimed to investigate the of early carbonation curing on different replacement ratio and type of treated RCSW including screening, shearing and ball milling. In addition to mechanical properties, hydration properties, and microstructure characteristics of the treated-RCSW replaced cement paste after early-age carbon and standard curing methods were investigated and compared. The results showed that, compared to 45% replacement ratio, the cement paste with 15% RCSW exhibited a higher strength. When comparing to standard curing, the carbonation curing method effectively improved the early strength and comprehensive performance of the cement paste, in which the early strength under carbonation curing was about 81.87 % higher than that of standard curing under the same conditions.

Keywords: Recycled concrete slurry waste; Carbonation curing; Pre-treatment; Substitution Rate; Compressive strength

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Study on the effect of sulfate erosion products on the pore structure of cementitious materials under dry and wet cycles based on GEMS simulation

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ABSTRACT

To investigate the evolution of generation products and pore structure of cementitious materials under the long-term action of dry-wet cycle coupled with sulfate, the microstructures and physical phase compositions of the generation products of cementitious materials under the above-mentioned coupling were analysed by means of XRD and MIP, as well as by combining with the thermodynamic simulation (GEMS) and the kinetic (PK) model of cement hydration. Results show that: when the specimen in 5% sodium sulfate solution in wet and dry cycle 180d, with the increase of the number of wet and dry cycle, the average pore diameter of the specimen firstly decreases and then increases; pore fractal dimension shows a tendency of firstly increasing and then decreasing, and it reaches the maximum at 120 times of the wet and dry cycle, at this time, the most complex pore structure characteristics. GEMS combined with PK model simulated the erosion products of cementitious materials under different temperatures and erosion regimes and determined the changes in the quality of pore solution and hydration products. The results show that the erosion products of the specimen are mainly calcium alumina and gypsum, and the calcium alumina increases continuously to fill the pores under sulfate conditions, and when the erosion effect of sulfate is larger than the filling effect of the products, the formation of product excess makes the specimen's internal structure expand, which is the main reason for the deterioration of mechanical properties. Increasing the water-cement ratio and low temperature environment will increase the erosion products, significantly reducing the specimen's ability to resist sulfate erosion. In addition, the formation products of specimens under different regimes of 5% Na_2SO_4 internal doping and immersion were simulated, and result found that the endogenous erosion was more severe than the exogenous erosion, with more erosion products.

Keywords: Thermodynamic simulation; Kinetic modelling of cement hydration; Wet and dry cycles; Sulfate erosion: Pore structure

POSTER

Properties of carbonated steel slag admixture in the cementitious system

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ABSTRACT

Global warming caused by carbon dioxide (CO_2) emissions has emerged as an undeniable environmental concern. While advocating for energy conservation and emissions reduction, the challenge of addressing the substantial CO_2 emissions cannot be underestimated. Currently, steel slag is utilized in carbon capture and storage technology due to its potential for carbonation. However, the carbonation of steel slag necessitates a stable and cost-effective carbon source. Industrial exhaust gases are considered a viable option, but they often have low CO_2 concentrations, resulting in sluggish carbonation rates. Therefore, this study focuses on directly converting steel slag powder into concrete mineral admixtures to enhance the carbonation rate at low CO_2 concentrations. Experimental results reveal that a carbonation time of 3–7 days, a liquid–solid ratio of 50%, and the selection of sodium silicate as the alkali activator yield the optimal carbonation conditions. Under these conditions, the CO2 uptake can reach 15.3%–16.0%, and the f-CaO content can be reduced to 0.2%–0.3%. Mixing 30% carbonated steel slag powder with P.I 42.5 cement in mortar samples yields a compressive strength of 32.1 MPa at 7 days and 47.5 MPa at 28 days, along with a flexural strength of 6.2 MPa at 7 days and 8.0 MPa at 28 days. The addition of carbonated steel slag powder not only enhances the mechanical properties but also reduces the pore diameter in the hardened cementitious system. In 7 days, the pore size decreases from being concentrated around 349nm to approximately 282 nm, and in 28 days, the pore size decreases from being concentrated around 62nm to roughly 55 nm. This transformation is primarily attributed to the role played by calcite grains in the carbonated steel slag powder, which facilitates nucleation and filling effects.

Keywords: CCUS; Steel slag; Carbonation; Mineral admixtures

The hydrophobic polyelectrolyte multilayer - CSH membrane for improved separation of organic solvent

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ABSTRACT

Organic solvent nanofiltration (OSN) is a promising separation technology for removing solute from an organic medium. However, the fabrication of OSN membranes with stable separation performance is still a challenge. Herein, a hydrophobic polyelectrolyte multilayer membrane was prepared through a layer-by-layer self-assembly and counterion exchange method. The polyelectrolyte multilayer was self-assembled on the surface of the hydrolyzed polyacrylonitrile substrate through electrostatic interaction. Simultaneously, calcium silicate hydrate (CSH) nanoparticles were in situ grown during the multilayer formation process due to the incorporation of precursor in polyelectrolyte solutions. Therefore, the surface roughness of the membrane was enhanced and the anti-swelling property of the polyelectrolyte multilayer was also improved. The obtained hydrophilic $[(PDDA/PAA\text{-}CSH)2.5]^+Cl^-$ membrane was then converted to the hydrophobic membrane through the counterion exchange between Cl^- and PFO^-. The prepared $[(PDDA/PAA\text{-}CSH)2.5]^+PFO^-$ membrane has a water contact angle of 118°, which can be used to separate dyes from ethanol. The separation performance and stability of the polyelectrolyte multilayer membrane were improved through the in situ growth of CSH nanoparticles and counterion exchange by PFO^-. Therefore, this strategy may open a new avenue to prepare membrane for effectively separating and recovering organic solvents.

Keywords: Counterion exchange; Hydrophobic surface; Polyelectrolyte multilayer membrane; Organic solvent nanofiltration; Separation performance

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Lime mud-based lightweight artificial aggregate concrete

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ABSTRACT

Lime mud (LM), a solid waste generated in the paper-making industry, was proposed to manufacture lightweight artificial aggregates (LAAs) via the crushing technique. LAAs with a loose bulk density of 765–885 kg/m^3, an apparent density of 1270–1445 kg/m^3, and a strength of 5.7–7.2 MPa were achieved in this study. To optimize the crushing consumption energy and the mechanical properties, the mix proportions and curing ages of the LAAs before crushing were comprehensively investigated through mineralogy and microstructure analyses. In addition, the embodied carbon and material costs of the manufactured LAAs were estimated. Results showed that the early crushed LAAs (curing till 28 days) enabled achieving the higher 28-day strength compared to the 28-day-crushed LAAs; however, the early-crushed LAAs tended to produce more contents of powder. The incorporation of silica fume reduced the contents of crushing powder and refined the pore characteristics of the LAAs. Furthermore, optimized LAAs were used to manufacture the LAA concrete, where a deep understanding of the microstructural and micromechanical characteristics of the interfacial transition zone (ITZ) was investigated. The results indicate that the ITZ in LAA concrete has significantly lower porosity and higher elastic modulus and hardness compared to that in natural aggregate concrete, mainly attributed to the water absorption effect of LAA and the internal curing of LAA concrete. The EDS results show that the Ca/Si molar ratios of ITZ in 28-day LAA concrete varies between 1.0 and 2.0, and the waveforms of the Ca/Si curve become steeper as the curing age increases. XRD analysis reveals that the leaching of Ca^{2+} from LAAs leads to an increase in the content and orientation index of CH crystals at the interface, which may not be favourable for interfacial bonding.

Keywords: Lightweight artificial aggregates; Internal pore structure; Energy optimization; Carbon footprint

Evaluating the environmental performance of LC^3 in the UAE: a comparative study of different clay reactivities

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ABSTRACT

This life cycle assessment (LCA) study evaluates the environmental performance of introducing limestone calcined clay cement (LC^3) in the UAE using clays from the UAE, Oman, and India. Thermogravimetric Analysis (TGA) results revealed varying reactivity among the clay sources. The strength development was also investigated for the LC^3 mortar samples compared to ordinary Portland cement (OPC) mortar. The LCA quantified the CO_2 equivalent (eq.) emissions for all LC^3 mortar samples, including the clay transportation emissions, and compared it to that of OPC mortar using the IPCC GWP-100 indicator. LC^3 mortars using UAE, Oman, and India clay demonstrated 38%, 39%, and 27% CO_2 eq. reductions, respectively, compared to OPC mortar. The CO_2 emissions were normalized by the 28-day strength values to provide a more nuanced understanding of the environmental impact in relation to mechanical performance. LC^3 mortar using Oman clay demonstrated a 34% reduction in normalized GWP compared to OPC mortar, which was significantly higher than that obtained by the LC^3 mortar using high-reactivity clay from India compared to OPC mortar. These results provide useful insights for implementing LC^3 as a decarbonization strategy in the UAE cement industry, considering both the location and reactivity of the clay source.

Keywords: LC^3; Life cycle assessment; Normalized emissions

Carbon emission assessment of coral aggregate concrete in reef environment based on LCA model

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ABSTRACT

In order to promote the implementation of the strategy of Maritime power and Double carbon, a life-cycle carbon emission evaluation model was proposed with coral aggregate concrete (CAC) and Low carbon coral aggregate concrete (LCCAC) as research objects, and the carbonization and strength grade of concrete were considered. The evaluation method of concrete carbon emission per unit strength and per unit year was established. The results show that cement is the main source of carbon emissions in the production stage of raw materials, accounting for more than 80%, and local materials can reduce carbon emissions by more than 50% in the transportation stage of raw materials. The life cycle carbon emission and unit strength carbon emission of CAC and LCCAC increased with the increase of strength, but the annual carbon emission decreased with the increase of strength. Compared with CAC, LCCAC can effectively reduce the carbon emission of the life cycle, and the carbon reduction rate is 2.15%~2.33%, which has obvious carbon reduction benefits.

Keywords: Coral aggregate concrete; Life cycle; Carbonization; Carbon emissions; Evaluation method

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Prediction of compressive strength of calcium sulfoaluminate cement by interpretable machine learning model

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ABSTRACT

Organic solvent nanofiltration (OSN) is a promising separation technology for removing solute from an organic medium. However, the fabrication of OSN membranes with stable separation performance is still a challenge. Herein, a hydrophobic polyelectrolyte multilayer membrane was prepared through a layer-by-layer self-assembly and counterion exchange method. The polyelectrolyte multilayer was self-assembled on the surface of the hydrolyzed polyacrylonitrile substrate through electrostatic interaction. Simultaneously, calcium silicate hydrate (CSH) nanoparticles were in situ grown during the multilayer formation process due to the incorporation of precursor in polyelectrolyte solutions. Therefore, the surface roughness of the membrane was enhanced and the anti-swelling property of the polyelectrolyte multilayer was also improved. The obtained hydrophilic $[(PDDA/PAA\text{-}CSH)2.5]^{+}Cl^{-}$ membrane was then converted to the hydrophobic membrane through the counterion exchange between Cl^{-} and PFO^{-}. The prepared $[(PDDA/PAA\text{-}CSH)2.5]^{+}PFO^{-}$ membrane has a water contact angle of 118°, which can be used to separate dyes from ethanol. The separation performance and stability of the polyelectrolyte multilayer membrane were improved through the in situ growth of CSH nanoparticles and counterion exchange by PFO^{-}. Therefore, this strategy may open a new avenue to prepare membrane for effectively separating and recovering organic solvents.

Keywords: Calcium sulfoaluminate cement; Machine learning; Compressive strength; XGBoost; SHAP

Biomimetic cement-resin composite with integrated high strength and toughness

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ABSTRACT

To enhance the toughness of concrete, a biomimetic cement-resin composite featuring integrated high-strength and toughness was developed, drawing inspiration from the hierarchical structure observed in shell nacre. The aluminate cement and organic polymers were utilized to construct the organic-inorganic system within the biomimetic composites. The quasi-static and dynamic mechanical properties of the biomimetic composites were investigated using the three-point bending and drop-hammer impact tests, respectively. Furthermore, the strengthening-toughening mechanisms of the biomimetic composites were elucidated through scanning electron microscopy and finite element modelling techniques. Results indicated that the proposed composites possess a remarkable combination of high strength (≈66.1MPa), toughness (≈854.18kJ·m^{-3}), and exceptional impact resistance. This composite significantly outperforms the cement counterpart in static toughness and impact energy, by factors of approximately 700 and 600 times, respectively. It was demonstrated that the "brick-bridge-mortar" structure incorporated into the composites played a critical role in deflecting cracks and dispersing stresses, contributing to the integrated high-strength and toughness of this composite. The developed biomimetic composites provide a new solution for addressing the challenges of enhancing toughness and reducing brittleness in modern engineering materials.

Keywords: Biomimetic design; Cement-resin composite; Nacre-like structure; Gradient structure; Impact resistance

A study on utilizing heat-treated construction waste powders as Portland cement replacements

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ABSTRACT

This study investigated the effect of heat treatment of various construction waste powders for partial replacements for Portland cement on the mechanical properties of cement mortars. Three types of construction waste powders were used: fines generated while the production of high-quality recycled aggregate in a recycling plant, and two powders obtained by crushing once and twice recycled coarse aggregate concrete in a laboratory. To enhance activity, the powders were exposed to 600 °C and 800 °C for two hours, and their chemical composition before and after exposure was identified by X-ray diffraction. Mortar samples were prepared by replacing 20% of the Portland cement with the prepared powders, and their basic properties were subsequently investigated: flow in fresh state, compressive strength, water absorption and ultrasonic pulse velocity. The experimental results showed that the inclusion of heat-treated powder in the mortar slightly reduced the flow but improved its hardened properties. The 28-day compressive strength of mortar containing heat-treated powder at 600 °C increased by 4-10% compared to that without heat treatment, while at 800 °C, the compressive strength increased by 13-21%. In particular, the fines generated during the production of high-quality recycled aggregate exhibited greater heat treatment efficiency compared to other powders, thereby demonstrating the applicability of heat treatment to actual construction waste.

Keywords: Concrete recycling; Green cement; Thermal treatment; Multi-recycling; Supplementary cementitious material

Study on failure characteristics of multiple interface transition zone of recycled coarse aggregate concrete

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ABSTRACT

Due to the difference of quality grade of recycled coarse aggregate, the type of the failure interface in recycled concrete is influenced by many factors, exhibiting significant uncertainty. This paper takes the recycle aggregate multiple interface transition zone as the starting point, with the help of micro hardness, fracture energy, interface porosity based on backscattered electron imaging and other micro characterization methods. The relationship between the fine and micro parameters of different types of interfaces and the failure order of recycled concrete was studied. The test results show that the fine and micro parameters could predict the interface with priority failure to a great extent. The interface transition zone with low fracture energy, high porosity and low hardness value shows high consistency with the interface with the first signs of failure. Through the analysis of digital image correlation technology, it can be found that the interface with the first signs of failure also shows strong strain evolution fluctuations. The research results would provide effective reference for targeted recycled aggregate repair.

Keywords: Recycled aggregate; Failure mechanism; Multiple interface transition zones; Strain evolution; Nano-modification

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Effect of MSWI fly ash solidification products on hydration and hardening of gypsum slag cement

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ABSTRACT

The stabilization of heavy metals can be achieved by converting municipal solid waste incineration (MSWI) fly ash into ettringite and calcium sulfate dihydrate. In addition, the content of chloride ions in the new solid phase is less than 0.5%, which has the potential application in civil engineering materials. In this work, a new cementitious material was prepared by combining MSWI fly ash converted ettringite and calcium sulfate dihydrate with slag and desulfurized gypsum. The results show that good matrix strength can be obtained when the content of ettringite and calcium sulfate dihydrate converted from MSWI fly ash is 25%, slag is 70% and desulfurized gypsum is 5%. The early strength of gypsum slag cement was improved by adding ettringite converted from MSWI fly ash and calcium sulfate dihydrate. C-(A)-S-H gel filled in the pores crossed by ettringite making the structure of the matrix denser, thus ensuring the later strength development. C-(A)-S-H gel can play a role in the secondary solidifying of heavy metals in MSWI fly ash conversion products. The heavy metals in the new cementitious materials have no leaching risk.

Keywords: MSWI fly ash; Gypsum slag cement; Cementitious material; Heavy metal; Solidification

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A study of the workability and early hydration of natural hydraulic lime with polycarboxylate superplasticizer

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ABSTRACT

The effects of polycarboxylate superplasticizer on the workability and early hydration characteristics of freshly mixed NHL slurry were systematically investigated. Factors such as the dosage of polycarboxylate superplasticizer, water-cement ratio, and aging time were thoroughly discussed. Freshly mixed NHL slurry was prepared with a water reducing agent content ranging from 0 to 0.2% and a water-cement ratio ranging from 0.5 to 0.8. The temporal fluidity, rheological properties, viscoelasticity, hydration kinetics and heat release, as well as the phase composition and evolution of NHL slurry at an early stage (3 days ago), were experimentally examined. The experimental results demonstrate that increasing the water-cement ratio and incorporating a water reducing agent can effectively reduce the yield stress and plastic viscosity of the slurry while significantly improving its rheological properties. Pure NHL slurry exhibits only viscoelastic and elastic behavior; however, with the addition of polycarboxylate superplasticizer, it also acquires pure viscous characteristics within 30 minutes. Moreover, high water-cement ratios along with the presence of a water-reducing agent hindered the early hydration process in NHL slurry by limiting calcium hydroxide and calcium silicate hydrate formation. This study provides a theoretical foundation for utilizing NHL grout in practical applications.

Keywords: Natural hydraulic lime; Polycarboxylate superplasticizer; Rheological properties; Viscoelasticity; Early hydration

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Microstructure and mechanical properties of strain hardening cement-based composites (SHCC) by activated recycled concrete micropower

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ABSTRACT

Recycled micro-powder is an environmentally friendly product prepared by using special equipment to screen, break, physically strengthen, refine and grind construction waste. Based on the analysis of the chemical composition, microstructure, activity index, and other characteristics of the recycled concrete micro-powder (RCP), the effects of the replacement rate of RCP and fly ash, the curing time on the basic mechanical properties of SHCC were compared. The crack pattens of SHCC under different strain were obtained by digital imaging technology. The microcrack formation mechanism of SHCC was analyzed by mathematical statistics and probability methods. The compressive constitutive model of RCP-SHCC was established and the toughness indexes of each group were calculated, and the influence of RCP on the mechanical properties of SHCC was proved. Results showed that under the same substitution quantity, the strength of RCP-SHCC was higher than FA-SHCC, but the ductility was lower than FA-SHCC. The reason was that RCP has a high content of $CaCO_3$. In addtion, there were a lot of needle-rod ettrinite and non-dense areas in the interfacial transition zone. However, their properties meet the engineering needs. This study has reference significance for the application of RCP in SHCC.

Keywords: Strain hardening cement-based composites; Recycled powder; Mechanical property; PVA fiber

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Effects of temperature and fly ash content on hydration and corrosion resistance of high-ferrite Portland cement

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ABSTRACT

The comparative analysis of the hydration characteristics and corrosion resistance of high-ferrite Portland cement (HFPC) was conducted, focusing on the effects of temperature and fly ash (FA) content. The results show that with the increase of fly ash content, the mortar conductivity first decreases and then increases. When the fly ash content is 40%, the conductivity of the mortar reaches the minimum. when When the fly ash content is within 40%, the flexural and compressive strengths of the mortar do not decrease significantly with increasing erosion time. However, when the fly ash content exceeds 60%, the mortar strength decreases significantly with increasing erosion time. Furthermore, the incorporation of fly ash in HFPC paste results in a notable reduction in hydration heat release rate, particularly at higher temperatures. Additionally, the corrosion resistance of HFPC-FA paste in various salt solutions improves with the increase in curing temperature and the addition of fly ash, further highlighting its durability and performance advantages. Therefore It is recommended that the fly ash content in HFPC paste should not exceed 40% for practical applications and it has more advantages when used in high temperature environments.

Keywords: High-ferrite Portland cement; Temperature; Fly ash; Hydration heat; Corrosion resistance

Natural fibre-enhanced CO_2 transport and uptake in cement pastes subjected to enforced carbonation

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ABSTRACT

This study explored the use of untreated natural fibre yarns (jute, hemp, cotton, wool) to enhance CO_2 transport in cement pastes during enforced carbonation (20 vol.% CO_2, 1 atm, 24-168 hours). Unlike short dispersed fibres, which offer limited control over the connectivity of pore channels, these yarns establish interconnected channels that direct CO_2 transport in specific orientations. The intrinsic porosity of the yarns creates additional pathways in the cement matrix, thereby increasing the surface area available for carbonation reactions and promoting deeper CO_2 penetration. Carbonation profiles were assessed with image analysis and thermogravimetric analysis. A novel image analysis approach, based on colour deconvolution and overflow segmentation, was developed to quantify the carbonated area fraction. The findings from image analysis correlated well with the CO_2 uptake measurements obtained through TGA, validating this method as an efficient tool for rapidly assessing carbonation in cement-based materials. The results confirmed that the natural fibre yarns created preferential CO_2 transport pathways to facilitate CO_2 uptake. Hemp yarns resulted in the most significant enhancement in carbonation rate, with a 37.7% increase in average CO_2 uptake within 3 days, and 45.1% increase within 7 days and compared to non-fibre samples. This study established a fundamental understanding for controlled CO_2 transport and uptake within these composites, and demonstrated the potential of employing more complex natural fibre yarns arrangements in future research.

Keywords: Carbonation; Curing; Fiber reinforcement; Image analysis; Thermal analysis

Improving the properties of amorphous precipitated silica as supplementary cementitious material

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ABSTRACT

Olivine is one of the most abundant minerals in the world. Through acid digestion, amorphous precipitated silica (APS) can be produced. APS can be used as a viable supplementary cementitious material (SCM) to lower the carbon emission of Portland cement and concrete materials. However, APS have a high surface area and water demand which can affect workability. This research aims to investigate the potential of short thermal treatment at 400°C to 1000°C to improve the characteristics of APS and the performance of cement-based materials containing APS. The effect of heat-treated APS at different Portland cement replacement levels on workability and early strength of mortar were studied. The results showed a significant decrease in surface area and an increase in amorphous content and pozzolanic reactivity (R^3, ASTM C1897-20) of heat-treated APS. Mortar with APS replacement showed lower workability and the addition of 2 wt.% superplasticizer is required to achieve a flow like pure Portland cement mortar. Replacement of Portland cement at 10 wt.% yielded an early strength that is 1.2 times higher than PC reference.

Keywords: Olivine; Pozzolanic reaction; Flow table; Supplementary cementitious materials; Amorphous silica

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A special tribute to the bicentenary of Joseph Aspdin's patent for Portland cement!