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1ST INTERNATIONAL CONFERENCE ON INNOVATION IN LOW-CARBON CEMENT & CONCRETE TECHNOLOGY

LONDON 24-26 JUNE 2019

Editors: Yun Bai, Sam Ghazizadeh, Raman Mangabhai, Shi Shi, Judith Zhou





Proceedings of the 1st International Conference on
Innovation in Low-Carbon Cement & Concrete Technology

Held at
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24-26 June 2019

Edited by
Prof Yun Bai
Dr Sam Ghazizadeh
Raman Mangabhai
Dr Shi Shi
Dr Judith Zhou

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PREFACE

The construction industry has been under pressure to shift towards sustainability by manufacturing Portland cement in a more energy saving way and/or by developing alternative binders whose manufacturing process emits less CO₂. However, industrial applications are still scarce due to the gap existing between the fundamental research and the industrial use as well as the lack of standards and a skilled work force in this area.

To address these issues, the Advanced and Innovative Materials (AIM) Group at University College London (UCL), in collaboration with China Building Materials Academy (CBMA), started an initiative sponsored by a Researcher Links funding under the Newtown Fund in 2016. The project, entitled 'Innovation in Low-carbon Cement and Concrete Technology', was aimed at bringing together the communities of cement chemists, concrete technologists, engineers and physicists from both academic and industrial background from the UK and China to share their latest research outcome and innovations in order to promote industrial application of low-carbon cement and concrete. It was at this Researcher Links workshop organised at UCL on 21-24 September 2016 that the team at UCL was encouraged by the participants to further expand this initiative into an international conference where academics and industry could come together to explore and promote the practical ways of reducing carbon footprint for construction sector.

After more than two years of hard work, here comes our 'First International Conference on Innovation in Low-Carbon Cement and Concrete Technology (ILCCC2019)' where we have gathered participants from both industry and academia to exchange ideas on the use and application of alternative cements and discuss the low carbon roadmaps for the global cement and concrete industries. The organising committee is also honoured to be able to celebrate Professor Fredrik Glasser's 90th birthday and acknowledge his outstanding contribution to cement science, especially in the development of cements with a low carbon footprint, at this event.

The conference received more than 150 abstracts from more than 24 countries, only around 100 of which have been accepted for presentation. The conference is organised into 4 plenary sessions and 12 parallel sessions, including 12 keynote presentations, 80 oral presentations and 20 poster presentations on various topics, including alkali activated materials, alternative clinkers, carbonation and CO₂ curing, durability, emerging technologies, magnesium-based systems and waste utilisation. The editors hope that the participants will find the sessions useful and that the event can stimulate further research in the field.

The editors would like to thank all sponsors, exhibitors and advertisers for their support, without which the conference would have not been possible. We also wish to thank the international scientific committee for reviewing the papers and the Institute of Concrete Technology, the Institute of Materials, Minerals and Mining, the American Concrete Institute, the Mineral Product Association, Réunion Internationale des Laboratoires et Experts des Matériaux, Global Cement and Concrete Association and Soubte New Materials for supporting the event.

The conference will take place regularly, currently scheduled for every three years, to follow from the 2019 event and continue to report on the latest global scientific and technical achievements on low-carbon cement and concrete technology.

Prof Yun Bai

Dr Sam Ghazizadeh

Mr Raman Mangabhai

Dr Shi Shi

Dr Judith Zhou

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The advanced & Innovative Materials (AIM) group is based at University College London (UCL). AIM promotes industry-driven, interdisciplinary research in material science and engineering with a view to provide leading-edge, sustainable solutions to the challenges facing engineers in today's changing society and environment.

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The Institute of Concrete Technology

The Institute of Concrete Technology is the concrete sector's professional development body. It was formed in 1972 and aims to promote concrete technology as a recognised engineering discipline and consolidate the professional status of practising concrete technologists worldwide. Full membership is open to all those who have obtained the ICT's diploma or equivalent MSc in Advanced Concrete Technology. An alternative route exists for those with equivalent experience and qualifications. However, there are various grades of membership from Student upwards that reflect a candidate's experience and competency. Graded membership is to encourage participation from concrete technologists from an early stage in their career. The Institute is internationally recognised, and the Diploma has worldwide acceptance as the leading industry qualification in concrete technology. The Institute sets high educational standards and requires its members to abide by a Code of Professional Conduct. The Institute is also a Professional Affiliate of the Engineering Council and facilitates the registration of candidates as Chartered or Incorporated Engineers.

www.ict.concrete.org.uk



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The Institute of Materials, Minerals and Mining (IOM3) is a major UK engineering institution whose activities encompass the whole materials cycle, from exploration and extraction, through characterisation, processing, forming, finishing and application, to product recycling and land reuse. It exists to promote and develop all aspects of materials science and engineering, geology, mining and associated technologies, mineral and petroleum engineering and extraction metallurgy, as a leading authority in the worldwide materials and mining community.

www.iom3.org



The International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM, from the name in French) was founded in June 1947, with the aim to promote scientific cooperation in the area of construction materials and structures. The mission of the association is to advance scientific knowledge related to construction materials, systems and structures and to encourage transfer and application of this knowledge world-wide.

www.rilem.net



The American Concrete Institute (ACI) is a leading authority and resource worldwide for the development, dissemination, and adoption of its consensus-based standards, technical resources, educational & training programs, certification programs, and proven expertise for individuals and organizations involved in concrete design, construction, and materials, who share a commitment to pursuing the best use of concrete.
www.concrete.org



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.
www.mineralproducts.org



The Global Cement & Concrete Association (GCCA) is a CEO led initiative. It is the trusted, authoritative platform and voice for the cement and concrete sector across the world. Its aim is to drive responsible industry leadership in the manufacture and use of cement and concrete, whilst striving to improve the global social and environmental impact of the sector's activities and products. We aim to foster innovation and collaboration with all players across the built-environment value chain.
www.gccassociation.org

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and in 1497 it was first in the English-speaking world to create a chair of medicine. In 1793 the Original Chair in Chemistry was established at Marischal College this was the first chair in Britain to be promoted for Chemistry as a subject rather than derived from a medical school. The home of chemistry in Aberdeen today is the Meston building which built in 1952.

Throughout the 20th century Aberdeen has consistently increased student recruitment, which now stands at 14,000. In recent years picturesque and historic Old Aberdeen, home of Bishop Elphinstone's original foundation, has again become the main campus site.

The University has also invested heavily in medical research, where time and again University staff have demonstrated their skills as world leaders in their field. The Institute of Medical Sciences, completed in 2002, was designed to provide state-of-the-art facilities for medical researchers and their students. This was followed in 2007 by the Health Sciences Building. The Foresterhill campus is now one of Europe's major biomedical research centres. The Suttie Centre for Teaching and Learning in Healthcare, a £20m healthcare training facility, opened in 2009. 2012 saw the opening of the £57 million Sir Duncan Rice Library in Old Aberdeen, a great modern building to match the splendour of the University's 500 year old campus. For the sciences a new state of the art Science teaching hub has been started due to be occupied September 2012. This will revolutionise the way practical science teaching will be conducted in Aberdeen.
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Jiangsu Sobute New Materials Co., Ltd, (Sobute), which contains a State Key Laboratory of High Performance Civil Engineering Materials, has already become the leader of R&D, large-scale production and professional technical service in the industry of concrete additives in China. The R&D center of Sobute focuses on the scientific research of concrete technology, including concrete admixture, supplementary material, HPC fabrication and application, concrete repairing, performance of concrete strain and cracking, evaluation and prediction of concrete durability etc. Sobute has made great achievements in the research field of cracking resistance of concrete, durability improvement and service life extension of major infrastructure projects, and multifunction civil engineering materials. It is worthy of note that most of these achievements have been successfully applied in major construction projects of China, which made a significant contribution for the concrete industry in China.



Wuhan UJOIN Building Materials Technology Co., Ltd. is a professional solution provider for control of concrete crack and structural self-waterproofing system. It is committed to improving concrete properties, effectively controlling concrete crack and solving the waterproofing problems through customized technical solutions.

The company is headquartered in Wuhan, Hubei, which has more than ten production bases in China, including a technologically advanced rotary kiln production base for light burned magnesium oxide, a mature expansion clinker production base and a fully automated closed special cement mortar production base. There are 40 regional marketing centers, which can provide services to more than 600 cities in China. Nearly 200 professional technical service personnel provide timely and professional technical services for various projects. The company's self-waterproofing system solutions of concrete structure and its products are now widely applied in the field of industrial and civil buildings, hydraulic engineering, nuclear power, national defense, petroleum and transportation etc. The technology solutions of grout sleeve splicing of rebars are widely applied in various types of prefabricated building in China.

With technology innovation as its core competitiveness, the company has been focusing on control of concrete crack and waterproof technology research for more than ten years. We have established a domestic professional concrete properties research laboratory and technology R&D center and signed a strategic cooperation agreement with the Institute of Building Materials Research China Academy of Building Research. The "CABR-IBM•UJOIN Technology Center" has been established for comprehensive technical cooperation. At the same time, it has established long-term and stable cooperation with more than 20 universities and scientific research institutions and more than 50 well-known experts in concrete industry, such as Tsinghua University, Nanjing Tech University, and Guangdong Research Institute of Water Resources and Hydropower etc, and which strives to build an industry intelligence platform. The R&D center has obtained more than 40 technical patents and presided over nearly 20 research achievements at the national, provincial and ministerial levels. The company is a high-tech enterprise in Hubei Province, which has participated more than 20 national standards and industry specifications, a national intellectual property advantage enterprise, a national quality integrity demonstration enterprise, a national water conservancy advanced practical technology certification, a national railway product practical certification and a Chinese green building selection product.

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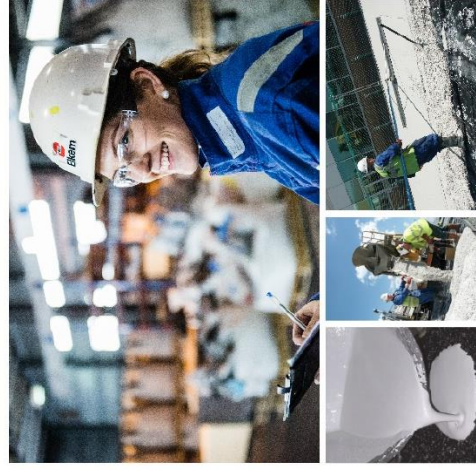


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KEYNOTE SPEAKERS



Fredrik Glasser
University of Aberdeen
United Kingdom

Fredrik Paul Glasser received his PhD from the Pennsylvania State University in 1957 where he worked on high temperature phase equilibria and refractories for the steel industry. In 1959, he moved to the University of Aberdeen, since then he has worked mainly on materials science, materials chemistry and solid state science and its applications. This has resulted in publication of more than 500 peer-reviewed articles. In recent decades, cements have featured prominently in his research portfolio. He is the recipient of numerous distinctions including a DSc (honorary, University of Aberdeen), Fellow of the Royal Society of Edinburgh, of the IoM3, the Mineralogical Society of America, Honorary Fellow of ICT, and a Distinguished Life Member of the American Ceramic Society. He is a founder fellow of the Academy of Ceramics and Chairman of the Editorial Board of Advances in Cement Research. He has contributed to International Science and was co-chair of the International Congress of the Chemistry of Cement (Gothenburg and was awarded the Torroja Gold Medal for services to science in Spain). He has been made a Burgess of the city of Aberdeen for civic services. After retirement, he continues to be active in research on the development of cements with low or negative embodied CO₂ and in the development of calcium sulfoaluminate cements.



Karen Scrivener
EPFL
Switzerland

Karen Scrivener obtained her PhD at Imperial College in 1984. She worked for Lafarge in France for 6 years, before being appointed Professor and Head of the Laboratory of Construction Materials, at EPFL, Switzerland in 2001. Her research focusses on the understanding the chemistry and microstructure of cement-based materials and improving their sustainability. She is editor in Chief of the leading academic journal "Cement and Concrete Research" and was made a fellow of the Royal Academy of Engineering in 2014.



Changwen Miao
Southeast University
China

Changwen Miao is academician of Chinese Academy of Engineering, professor and doctoral supervisor at Southeast University and the president of Jiangsu Research Institute of Building Science Co., Ltd. His research areas include: crack resistance of concrete; the advancement of service life and durability of significant infrastructure engineering; multi-functional materials for civil engineering. He has published 4 monographs and over 100 academic papers in highly ranked peer-reviewed journals. He is awarded over 80 state-level patent rights. Miao Changwen also serves as the Honorary Chairman of RILEM China National Group, Vice director of China Building Material Federation, Executive director of China Civil Engineering Society, Executive Director of The Chinese Ceramic Society, Vice director of China Concrete and Cement-based Products Association.



Johann Plank
Technische Universität
München
Germany

Johann Plank is full professor for Construction Chemistry and head of the Institute for Inorganic Chemistry at Technische Universität München. He studied chemistry in Regensburg, Germany and in 1980 earned a Ph.D. degree there. He then joined SKW Trostberg as a research group leader, construction polymers and founded SKW's oilfield chemicals business before he became General Manager of SKW Construction Polymers GmbH in 1997. In 2001, he joined Technische Universität München, Germany, as a full professor for Construction Chemistry. His current research interests include cement and admixture chemistry for concrete, gypsum, mortar and oil well cementing. Prof. Plank has published about 400 scientific papers, holds 40 patents in the field of construction admixtures and has received many awards and honorary professorships from universities in Japan, China, Singapore and Thailand.



Barbara Lothenbach
EMPA
Switzerland

Barbara Lothenbach is the head of the Thermodynamic Modelling Group in the Laboratory of Concrete and Construction Chemistry, Empa, where she has worked since 2002 and holds the International Chair at the Concrete Group, Department of Structural Engineering, NTNU Trondheim, Norway. She has obtained her PhD in 1996 from ETH Zürich, Switzerland. Her main research interests include: hydration of cements, in particular changes in hydrate assemblage and pore solution; the effect of supplementary cementitious materials; durability; thermodynamic modelling. One of her focus is the development of thermodynamic models to predict the changes in the solid and liquid phase during the hydration of Portland and blended cements as well as the changes caused by the interaction with the environment. She has initiated the thermodynamic databases for cement hydrates, Cemdata, which is based on numerous experimental solubility data determined by different groups worldwide. The Cemdata database is freely accessible (www.empa.ch/cemdata) and can be fully integrated in geochemical modelling software such as GEMS and PHREEQC.



Thomas Matschei
University of Applied Sciences
Dresden (HTW Dresden)
Germany

Thomas Matschei currently holds the chair of Concrete Materials and Repair at the department of Civil Engineering, HTW Dresden, Germany. He obtained his PhD in 2009 from University of Aberdeen, Scotland, United Kingdom, on "thermodynamics of cement hydration". His research interests include: thermodynamic modelling of cementitious systems including support for the development of the widely used thermodynamic dataset cemdata (latest version cemdata18); Prediction of phase relations in hydrated cements (Development of phase diagrams including new data on AFm-AFt phase assemblages and solid solutions e.g. showing the impact of limestone additions and changing water activities on the mineralogy of hydrated cements.); Research on novel cement and binder compositions (ternary binders based on CSA, understanding silicate-aluminate-sulfate interactions relevant to novel cements based on OPC, carbonation hardening cements); Understanding of phase relations relevant to the durability of modern cements (incl. chloride ingress, ASR, sulfate attack, DEF, etc.)



Muhammed Basheer
University of Leeds
United Kingdom

Muhammed Basheer, Chair in Structural Engineering and Head of School of Civil Engineering at University of Leeds, has been an educationalist and researcher in the field of civil (structural) engineering for 34 years. His research includes the development of new test techniques for measuring transport properties of concrete, assessment of the effect of new materials and methods for improving the durability of concrete, prediction of service life of reinforced concrete structures by non-destructive testing and structural health monitoring, relationships between micro-structural properties and the durability of concrete and the use of industrial by-products and waste materials in concrete. He has received numerous awards/prizes for his contributions in research, including a life time achievement award from the Civil Engineering Research Association of Ireland and CANMET/ACI award for his sustained contributions to the field of concrete technology. He is a member of the editorial board of the International journal of Structural Engineering (IJStructE) since 2009 and served as an editor of the International Journal of Construction and Building Materials from 2012 to 2018. In 2012, he was elected to be a Fellow of the Irish Academy of Engineering and in 2014 he was elected to be a Fellow of the Royal Academy of Engineering. He is also a Fellow of the Institution of Civil Engineers, Institution of Structural Engineers, American Concrete Institute, and the Institute of Concrete Technology.



Caijun Shi
Hunan University
China

Caijun Shi is currently a Chair Professor of College of Civil Engineering, Hunan University and China Academy of Building Materials Academy. He received his Ph.D from University of Calgary, Canada. He is the Editor-in-Chief of Journal of Sustainable Cement-based Materials, associate editor of Journal of Materials in Civil Engineering and Journal of Chinese Ceramic Society, and an editorial board member of Cement and Concrete Research, Cement and Concrete Composites, Construction and Building Materials. He is a member of many technical committees within ACI and RILEM. His research interests include: characterization and utilization of industrial by-products and waste materials; design and testing of cement and concrete materials; development and evaluation of cement additives and concrete admixtures, and solid and hazardous waste management. He has authored/coauthored more than 360 technical papers, six English books, three Chinese books and edited/co-edited seven international conference proceedings. He is a fellow of International Energy Foundation, a fellow of American Concrete Institute, and a fellow of RILEM.



Yun Bai
University College London
United Kingdom

Yun Bai is Professor of Construction Materials in the Department of Civil, Environmental & Geomatic Engineering (CEGE) at University College London (UCL). He is also Head of the Advanced and Innovative Materials (AIM) Group, Deputy Head of Civil Engineering Section and Co-Director of UCL-UDM Advanced Infrastructure Research Centre (UUAIR). He obtained his BEng. in Building Materials from Chongqing University, China in 1993. After working as a Civil Engineer in construction industry for nearly 7 years, he started his PhD in Queen's University Belfast (QUB) in 2000 and then received his PhD degree in 2004. Following his PhD, he worked as a PDRA in The Immobilisation Science Laboratory (ISL) at Sheffield University. In 2007, he re-joined QUB as a Lecturer before taking up a Senior Lecturer's post at UCL in 2012. He was then promoted to Reader in 2014 and Professor in 2018. The current research themes covered by his research group include: novel low-carbon cementitious materials, advanced composite materials, rheology of novel cement and concrete, durability of concrete structures, structural health monitoring and nuclear waste immobilisation. He is a Fellow of The UK Higher Education Academy (FHEA), The Institute of Concrete Technology (FICT) and The Institute of Materials, Minerals and Mining (FIMMM).



Mark Tyrer
Coventry University
United Kingdom

Mark Tyrer is currently Professor of Geomaterials and Executive Director of the Faculty Research Centre at Coventry University (appointed December 2016). In 1996, he took up a Fellowship at Imperial College, London, where he conducted industrial research in cement science, novel sorbents, mineral processing and resource-recovery and contributed to several books and five patents. In 2003 he set up an independent consulting practice, through which he worked as Research Manager for MIRO (the Mineral Industry Research Organisation) acting on behalf of commercial clients in a range of technical and advisory capacities, including BP; Shell; Britannia Refined Metals; Health and Safety Executive; Castle Cements; Tarmac Quarry Products Ltd.; Tarmac Southern Ltd.; Tobermore Ltd.; The National Physical Laboratory; Westminster Abbey (Cosmati Pavement Committee) and others. He currently serves on the British Standards committee B/516 (Cements) and on the Concrete Society Expert Working Group on the Analysis of Hardened Concrete. In addition, he is a former chairman of the Construction Materials Group of the Society of Chemical Industry and current Chairman of the Cementitious Materials Group at the Institute of Materials, Minerals and Mining. Mark Tyrer was elected as a Fellow of the Geological Society of London in 1993, a Fellow of the Institute of Materials Minerals and Mining in 2003, a Fellow of the Mineralogical Society of Great Britain and Ireland in 2013 and to the Min. Soc. Council in 2014.



Tongbo Sui
Sinoma International
Engineering
China

Tongbo SUI is the vice president of Sinoma International Engineering Co. Ltd., China Building Materials Group. He has been intensively engaged for over 20 years in R&D of low energy & low CO₂ clinker cements (mainly reactive belite-rich clinker and belite-ye'elimate clinker system) as a solution to addressing cement and concrete sustainability. He is also visiting professor at Tongji University, China and University College London, UK, and active in international organizations as member of the Climate Committee of World Cement Association and Co-Chair of Working Group 5 for Cement Innovation under Global Cement and Concrete Association. Before joining Sinoma in 2010, he worked since 1991 at China Building Materials Academy (CBMA) and as vice president of CBMA and director of UNIDO International Center for Technology Promotion during 2006-2010. He has presided over 10 state-funded key research projects in cement and concrete area as well as international cooperative projects with partners from Australia, Cuba, France, India, Japan, Norway, Switzerland, USA and Vietnam, etc. He is also the recipient of various awards including the 2nd class national prize for technological invention awarded by the State Council in 2006 for the R&D of low energy and low emission reactive belite-rich Portland cement, and international award for the outstanding contribution to the technology for cement and concrete sustainability issued at Seville, Spain in 2009 by the Organization of International Conferences for the Advances of Concrete Technology for Sustainable Development, ACI Council.



Mohsen Ben Haha
HeidelbergCement
Germany

Mohsen Ben Haha currently works as Team Leader Scientific Coordination of the Global Research and Development department at HeidelbergCement AG. He graduated from Ecole Polytechnique Fédérale de Lausanne with a PhD in "cement based materials". The main themes underpinning his research are: the development of high-performance building products that address energy consumption, waste use and emissions reductions; the development of innovative sustainable building materials and manufacturing practices solutions that reduce both the environmental impact and the waste generation during the production process; the increase of the level of substitution of Portland cement by traditional and novel SCMs beyond actual standards; the development of activation methods to enhance the reactivity of cementitious materials.



Claude Loréa
Global Cement and
Concrete Association –
Cement Director
United Kingdom

Claude Loréa leads all aspects of GCCA work related to cement, calling for a practical understanding of its chemistry, production, co-processing, data collection, standards as well as international climate policy, regulatory requirements and trends. With sustainability a key priority of the GCCA, she also leads the smooth transition of the activities of the Cement Sustainability Initiative to the GCCA and recently oversaw the publication of a 'Sustainability Charter' and 'Guidelines' for the industry. She is a member of the GCCA executive team based at the headquarters in London and recently launched a 'women in cement and concrete network'. Claude joined the GCCA from the European cement industry body, CEMBUREAU where she led on work for more than a decade, most recently as Deputy Chief Executive and Industrial Affairs Director. Over her career, Claude has built a detailed knowledge of the cement industry, including the sector's sustainability agenda where, among other achievements, she has led the development of the European Cement Industry Low Carbon Economy Roadmap. A Belgian national, she gained a degree in Civil Engineering from the University of Brussels before working as an environmental consultant and auditor. She gained her first hands-on experience of the cement industry as an environmental engineer with Cimenteries CBR in Belgium.

KEYNOTE LECTURES

The cement industry and its relation to energy and carbon dioxide

Fredrik Glasser

University of Aberdeen, United Kingdom

Portland cement manufacture is an energy-intensive process and is associated with high specific carbon dioxide emissions. Although the benefits of Portland cement construction arguably outweigh the intensity of its CO₂ emissions, we strive to lower the emissions associated with its production and use while, at the same time, seeking to improve its performance.

I concentrate on an example taken partly from my work with colleagues over past decades: Portland cement-calcium carbonate blended cements. Adding ground natural limestone to Portland cement is not new and specifications for Portland-limestone blended cements have existed for decades. What is relatively new is (i) the freedom to market a product fitting the legal requirements for Portland cement but containing up to 5% limestone, and (ii) the move to circularity resulting from the potential availability of synthetic CaCO₃ made from captured CO₂.

In assessing the action of limestone and of CaCO₃ in Portland cement blends, it is important to take a holistic view: the added carbonate /limestone has both physical and chemical impacts. The finer particles have a physical influence on cement performance, particularly on fresh mixes, but chemical reactions also occur. CaCO₃ is not simply an inert diluent but reacts with Portland cement during the hydration process affecting the mineralogical evolution, strength gain and physical qualities of the hardened product, such as strength and permeability.

In these respects, CaCO₃ differs from other cement admixes such as aluminosilicate fly ash and calcined clay because CaCO₃, has less impact on the high pH of cements than many other blending agents and this, in turn, enhances the durability of steel reinforced concrete in aggressive environments. By understanding and controlling the balance between physical and chemical reactions between cement and calcium carbonate, it may be possible to increase CaCO₃ contents without sacrifice of engineering properties and moreover, give scope for greatly enhanced reduction of net CO₂ emissions. The capture and conversion process and its implementation are described briefly as

initially operated. The process will scrub CO₂ from a coal-fired utility but the technology is readily transferrable to cement making.

It is proposed that in the decade ahead, an international effort be made to develop and exploit low-CO₂ versions of Portland cement. Many approaches have been proposed and there may be no "magic bullet". The industry has to coordinate internationally so standards can be developed and consumer protection assured. A serious and sustained effort will certainly achieve substantial environmental benefit and I predict with confidence that Portland cement will still be a preeminent construction material in the century ahead.

Lowering CO₂ emissions from cement production, practical realities and research needs

Karen Scrivener
EPFL, Switzerland

The production of cement is well recognised as one of the hardest sectors to decarbonise. This is because concrete, the final product is intrinsically already a very low CO₂ material, so it is difficult to go further and because most of the CO₂ emission come from the chemical decomposition of limestone. Nevertheless, because concrete (or cementitious materials is general) make up more than half of all materials we produce the associated CO₂ emissions are around 8% of man-made emission annually.

In this talk I will look at the prospects for reducing CO₂, which much take into account the practical realities of resources available and solutions which can be adopted at scale in developing countries where the demand for cement is highest available for producing cement. One of the best technologies capable of real implementation is LC3 (limestone calcined clay cement). Then I will look at the research needed to support further reductions in the long term. Here the main focus should be on the predictable performance of materials, on improving the early rate of strength development and on ensuring long service life. I will look at how we are progressing on these fronts.

Durability improvement of reinforced concrete and its engineering application in China

Changwen Miao
Southeast University, China

With the implementation of China national strategy for marine economic and infrastructure development, durability of reinforced concrete in infrastructure projects was challenged due to severe environment and long-life requirements. Therefore, research and application of new technologies for improving the durability of concrete is imperative for China's infrastructures. In this paper, recent research progress on the technology of durability improvement from the three aspects of concrete surface protection, corrosion resistance of concrete matrix, and corrosion resistance of reinforcement was presented. Firstly, the wet-based curing surface protection technology based on mussel bionics methodology and its engineering application was highlighted in this aspect. Secondly, cement hydration responsive nanomaterial was developed for strengthening importability of concrete with a characteristic of low water-cement ratio and high-volume mineral admixture, which has been applied to several bridge projects. At last, the new technology of corrosion inhibitor for reinforcement and its engineering application are also introduced.

Chemical admixtures for low carbon cement systems

Johann Plank

Technische Universität München, Germany

Low carbon cements will reduce the CO₂ footprint of the construction industry and therefore will become more dominant in the future. Such binders include geopolymer binders such as alkali-activated slags (AAS), calcined clays, ternesite cement, α -C₂SH and CSA cement, to name a few. However, their future acceptance and widespread use much depends on the availability of chemical admixtures which allow to control their workability, set behaviour, strength development etc.

In this presentation, experimental results on superplasticizers, set retarders and early strength enhancers for those binders will be introduced.

For AAS it was found that specific polycarboxylate (PCE) compositions which are soluble in the activator solutions are required to achieve dispersion and high workability. Whereas, for the other binders common PCE polymers which are currently used in Portland cement-based systems can be utilized. A specific problem for α -C₂SH is its high fineness which results in a higher water demand and exceptionally high PCE dosages.

From a world-wide perspective, calcined clays present by far the most attractive pathway to reduce the CO₂ emissions from cement manufacturing, as they allow to reduce the clinker factor by as much as 35%. However, this reduction comes with a significantly decelerated early strength development, compared to OPC. This disadvantage can be solved via addition of a novel early strength accelerator which is based on C-S-H-PCE nanofoils which act as seeding (nucleation) material. This admixture not only boosts the early reaction of the clinker portion in the blended cement; moreover, it also accelerates the pozzolanic reaction of the calcined clay, thus producing comparable early strength as for pure OPC.

Finally, it is shown that common set retarders such as sodium gluconate, citric/tartaric or boric acid and AMPS/acrylic acid copolymers work also well for those novel "green" binders except for the AAS binder. For this system, research to identify chemical structures with effective retarding properties is required.

Our investigations conclude that for these novel binders, the admixtures currently applied in OPC work in most cases, however, some specific gaps exist which need to be filled by new chemistries. Successful development of those admixtures presents the key for wide-spread utilization of any alternative binder material.

Hydrates in blended and non-Portland cements

Barbara Lothenbach
Empa, Switzerland

Thermodynamic modelling is essential to understand the effect of binder composition on hydrate assemblage in modern Portland composite cements and its effect on durability. Thermodynamic calculations have been applied not only to Portland cements, but also to blended Portland cements, to alkali activated systems, to calcium sulfoaluminate cements as well as to magnesium phosphate cements. Modelling is used to describe the changes during the hydration of cements as well as the effect of limestone and fly ash on the composition of hydrated PC and the effect of calcium sulfate, belite and limestone on hydrated calcium sulfoaluminate cements. The results can be summarized in binary and ternary diagrams to visualize the main effects of the clinker composition on hydrate assemblage and volume.

Engineering phase assemblages for sustainable cement design

Thomas Matschei
University of Applied Sciences Dresden (HTW Dresden), Germany

In the past thermodynamic models have often been considered as very theoretical and non-applicable to hydrating cementitious systems. However, over the last 20 years significant progress has been made to elaborate missing thermodynamic data of cement hydrates as well as to derive meaningful phase relations and stabilities in order to assess the basic properties e.g. stability of cement hydrates as function of temperature etc. This lecture will go one step further and tries to give an overview about the possibilities how to use thermodynamics to optimise cementitious systems to apply them more efficiently for engineering applications. The presentation will concentrate on three case studies:

1. Interaction between Aluminates and Silicates and the resulting applications to optimize cements by proper sulfate addition.
2. Application of thermodynamics to better understand durability phenomena related to carbonation and delayed ettringite formation.
3. Thermodynamic understanding of opportunities and limitations concerning fast drying binder systems.

The interactions between hydrating aluminates and silicates in Portland cement and the role of sulfate are subject of research over several decades. Recent studies have shown that high concentrations of alumina in the cement pore solution may induce an inhibitory effect on alite dissolution. With help of thermodynamic calculations, we could show that the addition of gypsum in presence of portlandite and ettringite, will suppress the equilibrium concentration of Al to very low levels, which explains the importance of sulfate optimization for an optimum cement design.

Concrete durability is typically expressed as sufficiently long service life of a structure without the need of excessive maintenance cost. Most damaging durability related phenomena can be attributed to deleterious phase transitions e.g. due to corrosion in the course of CO₂ exposure or chloride ingress, due to temperature fluctuations e.g. ice-water etc. Two examples will be discussed that are important to engineering applications: (i)

a more fundamental view on the risk of carbonation as consequence of cement composition and (ii) some recent findings on the risk of delayed ettringite formation in limestone blended systems.

In the last case study another driving force of phase transitions will be highlighted – which is a change of water activity. Here a few examples and related phase diagrams will be shown, how to apply thermodynamics in order to optimize the drying and shrinkage behavior of concretes e.g. for industrial floors.

In conclusion the lecture will show a number of practical examples how to apply thermodynamics to solve problems in modern Civil Engineering applications.

Suitability of alkali activated slag concretes for reinforced concrete structures in chloride environments

Muhammed Basheer

University of Leeds, United Kingdom

Alkali-activated slag (AAS) is a clinker-free binder with dense calcium silicate hydrate structure. Due to its high alumina content, it has the potential for high chloride binding capacity. A review of literature since 1980's has indicated that in some cases the chloride diffusion in AAS concrete is lower than the Portland cement (PC) counterparts and is comparable to concretes containing high volumes of supplementary cementitious materials, but this has not been found in all cases. Further, less is known about the effect of mix proportions, including binder content, water-binder ratio, role of activator, etc. on the rate of transport of chloride ions into AAS concretes. In addition, there is conflicting information on the ability of AAS concretes to delay both the onset and the rate of corrosion of embedded steel reinforcement. On the basis of a number of experimental investigations into AAS concretes, especially focusing on the permeation properties and the corrosion behaviour, it has been found that AAS concretes could achieve lower nonsteady state diffusion coefficient and higher degree of chloride binding, resulting in improved corrosion resistance. However, there is a need to choose mix proportions and the dosage of chemicals suitably because there was a significant influence and interaction between both Na₂O % and Ms of water glass.

Geopolymer concrete: Importance of mixture design

Caijun Shi
Hunan University, China

This presentation reports a general mix design procedure for alkali-activated slag-based concrete, which is an essential step towards industrial application of this new type of materials. The procedure includes 1) determination of coarse and fine aggregate ratio according to close packing model, as determined by measuring mixed bulk density; 2) determination of liquid phase (water content and activator) based on compressive strength; 3) determination of excess paste content by workability measurement. Effects of mix proportional factors, including activator composition, water content, fly ash content, and binder/aggregate ratio are examined on consistency, setting time and compressive strength. The relationship between performance and precursor composition is established using simplex centroid design method, by which a range of alkali-activated concretes with compressive strength grades of C40, C60, C80 and C120 are successfully prepared with initial setting time of 1 to 3 h and slump of more than 200 mm.

Manufacturing low-carbon cementitious materials with microwave curing: Opportunities and challenges

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Accelerated curing, such as steam curing, is widely used by construction industry to facilitate the development of high early strength of concrete in order to speed up the production process in precast plant. Although this can shorten the curing duration and bring some economic benefits, it is not that environmentally friendly due to the high energy consumption associated with the accelerated curing process. However, different from steam curing which is dependent on thermal conduction, microwave heating mainly relies on the conversion of electromagnetic power into thermal energy, which can result in a fast, volumetric heating. Since all the components of concrete are dielectric materials, particularly water, they can absorb microwave effectively and, thus, convert the electromagnetic energy into thermal energy efficiently and volumetrically.

In the past several years, a smart microwave system has been developed in the Advanced and Innovative Materials (AIM) Group at University College London by a consortium led by UCL. The key features of this microwave system include using optical fibre Bragg grating (FBG) sensors to control the temperature and the humidity inside concrete and microwave oven cavity, respectively. Research has also been ongoing in the AIM Group at UCL to explore the potential of manufacturing different low-carbon cementitious materials using this tailored-made microwave system. The recent results showed that even with 55% of Portland cement (PC) being replaced by fly ash, the concrete still can achieve 20MPa compressive strength after only 8 hours microwave curing. In the case of alkali-activated fly ash system where 100% fly ash is activated by an 8M NaOH solution without using PC, a 42MPa compressive strength can be reached within 6 hours microwave curing, which compared to the similar compressive strength achieved after 24 hours thermal oven curing at 85 °C, representing an 18-hour reduction of curing duration and 73% saving of energy consumption. In addition, attempts have also been made at UCL to use this microwave system as a novel preconditioning

technique for carbonation curing of cementitious materials. The latest results indicate that using microwave-based preconditioning, the compressive strength of cement mortar after carbonation curing can be increased by 30% as compared to the samples treated by the conventional thermal oven heating using a similar heating profile. The CO₂ uptake can also be increased by 38%. Additionally, compared to the preconditioning under low humidity environment, microwave-based preconditioning can save up to 95% of the preconditioning time.

Whilst all the current results obtained at UCL indicate there is a great potential of this innovative microwave curing technique for manufacturing low-carbon cementitious materials. Some challenges still need to be addressed before the industry can have sufficient confidence to adopt this technique. It is well-known that the highest curing temperature adopted by accelerated curing processes is mainly determined by the thermal stability of ettringite. However, under the electromagnetic field of microwave, it is not clear whether the thermal stability and microstructure could be affected. This is, in particular, a concern when the non-thermal effect of microwave is considered because this can potentially affect the activation energy and, hence, the microstructure and thermal stability of ettringite. On the other hand, the possible effects that the electromagnetic field of microwave may have on the formation of the passive film of steel reinforcements in concrete is also unknown, causing concerns over the durability performance of reinforced concrete cured by microwave. Furthermore, whether microwave could cause issues to the bond between concrete and rebar is another concern to the structural engineers. To address the above concerns, several research projects are also ongoing at UCL in an attempt to resolve the potential issues.

In this presentation, both these current progresses made at UCL and some future research challenges on using microwave curing will be presented and discussed.

Modelling of cement chemistry

Mark Tyrer

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Over the last twenty five years, the availability of low cost and high power computing has stimulated a huge expansion in modelling across all fields of science and engineering. During the same period of time, advances in experimental investigations of cement chemistry have increased our fundamental understanding of the mechanisms by which cements are produced, hydrate, perform in service and ultimately, may be recycled. Each of these stages has been simulated to help understand the chemical mechanisms prevailing and ultimately, to predict with reasonable confidence, the future evolution of cementitious materials. This presentation examines the methods used to model different aspects of cement science, comparing the fundamental approach with the conceptual and numerical models underlying a number of codes. From the smallest atomistic scale, through the huge advances in thermodynamic modelling, cellular automata and kinetic simulations, to coupled models which attempt to combine the simulation of chemical and physical mechanisms, we have a sophisticated toolkit at our disposal. The capability gaps between each field are closing and agreement of predictions from different approaches is increasing. Nonetheless, our work is incomplete and it is important to consider the current limits of our predictive ability, the lack of fundamental data in some areas and uncertainty of prediction. The presentation concludes by considering the current state of the art, our data needs and the likely developments in cement chemistry modelling in the foreseeable future.

Industrial effort on low carbon cements and application in China

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There are several best available technologies (BATs) and practices to reduce the energy consumption and environment impact of the key construction materials – cement. As outlined in the Global Cement Technology Road Map towards 2050 jointly launched by IEA/CSI in 2018, besides the technical levers such as energy efficiency, alternative fuels and clinker substitutes having been commonly regarded as BATs for cement sustainability, it is worth mentioning that alternative binding materials containing dicalcium silicate (C2S) and Calcium sulfoaluminate mineral (C4A3\$, CSA) were included in the new roadmap to offer potential opportunities for process CO₂ emissions reductions.

Industrial effort on the evolution of developing low energy and low carbon clinker cements, i.e., C4A3\$ based and C2S-based alternative binders through innovative clinker mineralogy since 1970s in China. Industrial effort on the development of CSA and reactive belite-rich Portland cement (i.e., high belite cement, HBC) and its modification through the introduction of CSA mineral in the clinker mineralogical design, i.e., belite-calcium sulfoaluminate mineral (BCSA) are reviews. The performance of these low carbon clinker cements and the resultant concretes as well as their field application are also introduced accordingly.

Recent progress on limestone calcined clay cement (LC3) in China is presented in terms of industrial trial effort in thermally activating the kaolinitic clay to make the LC3-50 cement with clinker factor of 0.5 while maintaining its 28d strength equivalent to that pure Portland cement.

Advances in understanding belite ye'elimite ferrite (BYF) cements

Mohsen Ben Haha

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In the last years, cement industry and academia progressed substantially in scientific understanding of belite-ye'elimite-ferrite (BYF) cements, a new, low CO₂ cement type primarily based on belite and ye'elimite. Industrial by-products were used as main raw materials for clinker production. It was possible to replace traditional raw materials, i.e. bauxite and limestone to high extents or even fully by industrial byproducts. One limiting parameter, for the substitution of these materials by industrial by-products, is the required ratio of silicon oxide over aluminium oxide in the raw mill and the targeted belite and ye'elimite content of the clinker.

The effect of the clinkering process on mineral formation and clinker reactivity has been investigated. Through a number of semi-industrial and industrial scale clinker production and cement grinding trials, a solid understanding has been developed on the key chemical/mineralogical parameters and process that determine clinker and cement performance. Additionally, the formation of ternesite was controlled thanks to special applied sintering procedure and/or kiln atmosphere. Ternesite, which is usually assumed to be inert, has shown reactivity potential when it is a part of calcium sulphoaluminate clinker.

Under given conditions, burning processes lead to variable clinker reactivity and sometimes to an uncontrollable early hydration. The presence of small amounts of mayenite (C₁₂A₇) in Fe-rich clinkers has shown to be responsible at least at lab scale of the kinetic variability of clinkers.

Through variations of the belite to ye'elimite ratio in the clinker, the level of sulfate addition and selection of the retarder and its dosage, the mortar and concrete workability and hardening characteristics can be controlled in a wide range. The very high early strength of BYF makes it a very favourable cement for pre-cast applications. Together with its very low shrinkage properties, BYF is also well suited for a wide range of other applications such as fast repair concrete or many mortar formulations, e.g. tile adhesives, screeds or repair mortars.

Low carbon roadmaps and pathways for the global cement and concrete industries

Claude Loréa

Global Cement and Concrete Association

Claude Lorea will feature the key learnings of the conference into her synopsis of low carbon roadmaps and pathways for the global cement and concrete industries and outline the GCCA work program with a special focus on low-carbon innovation. GCCA is the CEO led global sector initiative formed in 2018. Its three main priorities are establishing concrete as the sustainable building material of choice, promoting innovation across the industry, and building on the strong sustainability credentials of the sector. The GCCA innovation agenda is focussed on the low carbon transition. Key innovation areas GCCA intend to explore include innovation in cement production where many innovations have, and are, taking place, but with the need to meet the Paris Agreement, the focus is now on breakthrough technologies such as CCUS and process electrification. Modern cement plants operate today at, or close to, the theoretical limits of efficiency, and therefore deployment of CCS/U seems to be an essential technology in short/ medium term perspective to meet future global climate change goals. GCCA also intends to explore innovative cements including both new clinker substitutes and new types of clinker and binders, and new concrete mix designs – there are many interesting approaches in development and it is expected that from a mid-term perspective the new binding materials and systems will develop and enter the market for niche products. The versatility in constituents and mix lead to endless innovation. Claude Lorea will conclude on innovation in CCU and especially the ability of the cement and concrete sector to sequester CO₂.

ORAL PRESENTATIONS
Alkali Activated Materials

Alkali-activated cements based on metakaolin - Science and applications

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This paper provides a brief overview of the science and applications of alkali-activated cements based on metakaolin, in particular following the lines of enquiry and investigation that were opened by the pioneering work of Professor F.P. Glasser in this field (e.g. Palomo & Glasser, Br Ceram Trans J 91(1992):107-112). The influence of the work of Professor Glasser on later investigators entering the field will be explored, and the understanding that has been gained since that time will be summarised with a view toward identifying opportunities for deployment and exploitation of these cements in a practical sense. Applications ranging from infrastructure construction to waste immobilisation each offer interesting possibilities for this class of cements, and the factors that can lead to the design of high-performing, durable materials in each of the identified applications will be discussed from a scientific standpoint.

Investigation of chemically- and mechanically-based aeration techniques on alkali-activated MIDAR® cements [PDF](#)

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This study investigates the effect of several chemically- and mechanically-based aeration techniques on the pore structure, mechanical properties, shrinkage, thermal insulation and fire resistance properties of the alkali-activated MIDAR® cement system. Chemical blowing agents, including hydrogen peroxide, aluminium powder and silica fume, are investigated both separately and combined at different ratios and concentrations. The effect of varying the amount of commercial pre-foams incorporated into wet geopolymer slurries is also assessed. Tests with and without superplasticisers are also conducted to gain a deeper understanding of the interaction mechanisms of these organic admixtures with the highly alkaline environment of the geopolymer system. The results will allow a higher degree of control over the properties of foamed alkali-activated products, being more competitive and energy-efficient in comparison with Portland cement-based alternatives.

Nanoscale Ca-structure and its relation to the property development of various one-part activated slag materials [PDF](#)

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decreased the coordination number of the core Ca atoms, likely due to the higher degree of slag dissolution.

Alkali-activated materials (AAM) have been receiving increasing attentions as a potential replacement for ordinary Portland cement (OPC) in the aspect of reducing carbon dioxide emission. Although two-part AAM i.e., use of liquid activators is more conventional strategy in research area, one-part AAM i.e., use of powder activators is easier to utilize them in actual construction field as a form of bagged materials. This study investigated the slag-based AAM with six different activators varying chemically bound water such as MgO, Mg(OH)₂, CaO, Ca(OH)₂, Ba(OH)₂, and Ba(OH)₂·8H₂O. The mechanical performance and material characteristics were evaluated using compressive strength tests, isothermal conduction calorimetry, mercury intrusion porosimetry, and synchrotron-based Ca K-edge X-ray absorption spectroscopy.

Compressive strengths of the pastes with activators containing less bound water were superior to those with activators containing more bound water regardless of main elements in activators. However, the strength increments with activators containing less bound water decreased as the main element of activators (i.e., Mg, Ca, and Ba) became heavier. On the other hand, the activators with higher atomic number produced better compressive strength with denser microstructure. Although MgO-activated slag pastes generated high reaction heat and produced relatively high compressive strength, those Ca nano-structure such as Ca-O bond length and coordination number of the core Ca atoms were barely changed from those of raw slag. This result implies that MgO-activation for slag did not affect the Ca nano-structure of raw slag and its property development was not caused by the Ca structural changes. The increase of atomic number in activators increased the radial distance of Ca-O paths and

Applied mineralogy of Cemfree in comparison to OPC [PDF](#)

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The current widespread use of calcium silicate or aluminate hydrate binder systems as potential alternatives to OPC in the construction industry has its place in order to limit CO₂ emissions. Although strong alkaline activators, such as sodium hydroxide and sodium silicate solution are preferred for high strength, their manufacturing process is quite energy intensive. Therefore, Cemfree activator can be a friendlier alternative, typically with lower initial strength, but with similar hydration and microstructural behaviour as an OPC or other alkali activated materials. Microscopy and chemical analysis have played an essential part in developing our knowledge of Portland cement clinker phase composition, and it is routinely used to monitor cement quality. Thus, the same techniques, the ability to visualize, record and quantify phase composition, texture and further behaviour are being used to increase understanding of Cemfree binder, as an alternative to alkali activated material.

Development of alkali activated cementitious binder synthesised from metakaolin, volcanic tuff and lime waste [PDF](#)

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Conventional two-part alkali activated cement (AAC) is normally activated by alkaline chemical solutions such as (NaOH, Na₂SiO₃). These solutions are known of their hazardous and corrosiveness which in terms impede the utilisation of (AAC) in the construction fields. In this study, Metakaolin and volcanic tuff materials were used as alumina-silicate source. Lime waste material was used as an earth alkaline source to formulate mortars of one-part alkali activated cement with assistance of calcination (450 °C and 950 °C) to increase reactivity of starting materials. Materials were characterised by X-ray fluorescence, X-ray diffraction, and thermogravimetric analysis. Results proved that calcination process enhanced materials reactivity significantly by considerable variations in amorphicity and mineralogy of materials. Higher compressive strength for calcined lime waste in ternary blend was achieved and the influence of different level of calcination on compressive strength was revealed.

Resistance of fibre-reinforced fly ash-steel slag based geopolymer mortar to sulphate attack and drying-wetting cycle [PDF](#)

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Fly ash-steel slag based geopolymer mortar was studied with the aim of recycling solid wastes, and developing a sustainable alternative to Portland cement. The fibre-reinforced geopolymer mortar was prepared from the main raw materials of fly ash, steel slag, and fibre. This paper studies the mechanical properties, weight loss rates and appearance of fibre reinforced geopolymer explored under double-factor coupling, i.e. sulphate corrosion and drying-wetting cycle process on the geopolymer specimens.

The results show that compressive strength and flexural strength of each specimen gradually increased and tended to be stable under double-factor coupling. After 15 cycles, the compressive strength of the SF-4 sample (mixed with 0.4 vol. % steel fibre) is still the highest 67.9 MPa, and the compressive strength of the BF-3 sample (mixed with 0.3 vol. % basalt fibre) increases the most, whose growth rate is 96.6%. Due to evaporation of water and diffusion of sodium sulphate between specimens and solution, the change of weight loss rate of specimens was unstable. White precipitate was observed on the appearance of specimens, and it was sodium sulphate by X-ray diffraction (XRD) analysis. Both stable and compact structure of specimens and fibre-bridged matrix function make material have excellent in resistance to sulphate corrosion.

Using alkali-activated smart concrete for enhanced performance of structures [PDF](#)

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Building structures with resilience (structural health) can be achieved with a multi-component systems approach that combines the use of low carbon alkali-activated cementitious materials (AACMs) with embedded probes for service life tracking and online remote control in operation. AACMs are complex alumina-silicates that can be used as an alternative to Portland concrete (OPC) or, as we discuss here, in harmony with OPC to form more fire, chemical and environmentally resistant structures with inbuilt corrosion control. Blended from recycled and industrial waste by-products with no added heat provides a low carbon powder material with over 80% CO_{2e} savings compared to OPC.

This paper discusses special use of this material as a conductive impressed current cathodic protection (ICCP) anode mortar and concrete that provides compliance with ISO EN12696:2016 without the need for additional anode materials other than the casting of concrete. Embedded probes provide evidence of standard performance with remote control using open network electronics with online tracking of service life using corrosion rate data. Case studies are highlighted in both the restoration of reinforced concrete and historic masonry steel frame buildings as well as a prototype bridge beam precast from new with this technology inherent in the build. Data are also presented from research at Sheffield Hallam University that analyses the use of ICCP for maintaining concrete to reinforcement bond that has relevance to the design use of AACM anodes in new and existing constructions.

Formulation, performance, hydration and rheological behaviour of 'just add water' slag-based binders [PDF](#)

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The production of alkali activated binders as a dry-premixed powder which hydrates and hardens on blending with water effectively widens up the ease and scope of application of such systems. The choice of solid activation sets limits to the possible alternatives which are restricted to Na_2CO_3 , Na_2SO_4 and sodium metasilicate – available in the pentahydrate form $\text{Na}_2\text{SiO}_3 \cdot 5\text{H}_2\text{O}$. We have excluded the latter due to its hygroscopicity, its low grindability and its high embedded energy and CO_2 emission, which make it difficult to prepare and formulate the blends and reduce its potential environmental appeal.

The activation system not only determines the hydration kinetics and strength development, but it also affects properties like the fresh-state behaviour and sensitivity to the addition of dispersing admixtures – superplasticizers. The ionic composition of the interstitial solution depends on the activating agents, affecting both the solid surface potential – ζ potential – and the adsorption of anionic polymers.

Effect of Si and Ca on the reaction products, microstructure and strength of microwave cured alkali-activated fly ash

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Alkali-activated fly ash (AAFA) manufactured with microwave curing features a much lower carbon emission compared to the AAFA from conventional thermal curing due to the much shorter curing duration and more efficient heating mechanism of microwave. However, the main reaction product, sodium aluminosilicate (N-A-S-H) gel formed in the microwave cured AAFA is Al-rich (Gel 1) which could be converted to a more stable Si-rich N-A-S-H gel (Gel 2) at later stage, leading to a reduction in strength in the long-term. To maintain a stable strength, or even to have a continuous gain in strength, the Si-rich N-A-S-H gel should be formed during the early state of curing. In this paper, Si and Ca were introduced into the AAFA formulation to modify the Al-rich N-A-S-H gel formed during microwave curing. In addition to the compressive strength, the reaction products and microstructure were also characterised with XRD, FTIR and SEM. The results show that with the addition of 10% Si (in the form of waterglass), the formation of Si-rich Gel 2 is promoted due to the increased Si/Al ratio in the formulation. On the other hand, the addition of 10% Ca (in the form of $\text{Ca}(\text{OH})_2$) not only can consume some Al through the formation of calcium aluminosilicate hydrate (C-A-S-H) gel and, hence, increase the Si/Al ratio, but the coexistence of C-A-S-H gel and N-A-S-H gel has also been found to be able to further contribute to the strength gain of AAFA.

Alkali activation of blends of Fe-rich MSWI bottom ash and blast furnace slag

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Nowadays, much attention has been devoted to valorizing bottom ash (BA) from municipal solid waste incineration (MSWI). In this research, BA was introduced as binder additives in alkali-activated blast furnace slag (BFS) system to investigate the possibility of substituting BA for low-Ca coal fly ash (FA) in alkali-activated BFS/FA blends. The pastes made from FA/BFS blends were prepared as the reference. Characterization techniques, such as X-ray diffraction (XRD), X-ray fluorescence (XRF), and Vicat test, were used to evaluate the effects of BA addition on the properties of alkali-activated BFS. The results show that the addition of BA can dramatically increase the setting properties of alkali-activated BFS pastes, and this property enhancement is more significant than that achieved by adding FA. Alkali-activated pastes made from 30% BA with 70% BFS were found to have high compressive strength, but this strength is much lower than that of FA blended BFS samples.

Effects of novel curing techniques on the early hydration and mechanical properties of alkali-activated fly ash

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Alkali-activated fly Ash (AAFA), a low carbon and environmentally friendly material, has attracted the attention of many researchers worldwide. However, the strength development of this cementitious material is extremely slow at room temperature. Therefore, conventional thermal curing, such as steam curing (typically between 40 and 80 °C for at least 6 hours), is usually applied to initiate the chemical reaction at the early age in order to obtain reasonable strength needed for practical applications.

Although conventional thermal curing can significantly enhance the early hydration and strength development of AAFA, the energy consumption and ECO_2 are considerably high. In this study, two novel curing techniques, namely, a multi-stage microwave curing (MMC) technique and an electric curing (EC) technique, were separately employed to replace the conventional thermal curing in curing the AAFA. The results show that both the MMC and the EC can significantly improve the early compressive strength of AAFA. Additionally, when 5 wt.% of the fly ash was replaced with the floating beads or the magnetic beads in AAFA, the early compressive strength of AAFA cured with MMC can be significantly increased, indicating that the floating/magnetic beads can improve the efficiency of microwave heating. However, similar to the AAFA cured under conventional thermal curing, sodium aluminosilicate hydrates ('N-A-S-H' gel) and zeolites (Hydroxysodalite) have also been identified as the main hydration products in the two novel curing techniques.

Properties of geopolymer based on fly ash and metakaolin [PDF](#)

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The production of Portland cement is widely recognized as a major contributor of greenhouse gas emissions. This amounts to 6–7% of all the CO₂ emissions as documented in International Energy Agency. Therefore, numerous efforts have been made in the last decades either to reduce or to eliminate the use of Portland cement in concrete. Among various alternatives, geopolymer has attracted considerable attention because of its early compressive strength, low permeability, good chemical resistance and excellent fire resistance behaviour. This paper reports the strength and microstructure of various geopolymer mixes based on metakaolin and fly ash and fly ash alone. The compressive strengths were evaluated at 7, 14 and 28 days and microstructure were studied using SEM and XRD.

ORAL PRESENTATIONS

Alternative Clinkers

Belitic calcium sulfoaluminate cement: History, chemistry, performance, and use in the United States [PDF](#)

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Calcium sulfoaluminate (CSA) cements have generated significant interest from the academic community for their low carbon footprint. Often forgotten in this discussion is the development and the use of belitic calcium sulfoaluminate (BCSA) cement in the US for more than 30 years. This belite-rich CSA cement is sometimes presented as a recent innovation, but in reality, the production and use of this cement has already exceeded two million tonnes in North America. The main impetus for BCSA cement use was primarily its rapid strength properties, and therefore many airports and governmental agencies regularly use this cement for the rehabilitation of concrete pavement. The low-carbon footprint dimension was hardly considered during the early marketing of this cement. Fortunately, the extensive use of BCSA cement in the US provides a valuable case study on the viability and the durability of a CSA-based cement.

Alternative raw materials for the production of calcium sulfoaluminate cement: ladle slag and phosphogypsum [PDF](#)

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Calcium sulfoaluminate belite (CSAB) cement clinkers were produced using two industrial by-products: ladle slag and phosphogypsum. The phase composition of the produced clinkers was identified using quantitative XRD analyses, and the chemical composition of the clinker phases produced from phosphogypsum was established using FESEM-EDS. We demonstrate that ladle slag and phosphogypsum can be used as alternative raw materials for the production of CSAB cement. We also show that phosphorous from the phosphogypsum can be incorporated into the larnite crystal structure. The mechanical properties of the hydrated/hardened cement are also presented and are comparable with those produced from reagent-grade materials.

Belite formation and polymorphic transformation in belite-Calcium sulfo-aluminate clinker [PDF](#)

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The effect of clinkering conditions and the incorporation of Ti and S on the formation and polymorphic transformation of belite in Belite-Calcium Sulfo-Aluminate (BCSA) clinker has been investigated. BCSA clinker with approximate composition of 40 wt.% belite and 40 wt.% ye'elimite was designed and clinker produced at clinkering temperatures of 1270 °C, 1300 °C, 1320 °C and 1340 °C, each at three different time intervals 20min, 30min and 60min. The evaluation of belite's formation and polymorphic transformation in the clinker was performed by XRD/QXRD and SEM/EDS analysis. The increase of clinkering temperature and duration lead to the increment of the total belite in the clinker. In terms of polymorphism aH'-belite, typically formed at high clinkering temperature, appears to have its highest value at the lower clinkering conditions, most probably attributed on the presence and amount of Ti and S ions in belite crystals.

Calcium sulfoaluminate cement incorporating calcined clay and limestone – effect on hydrate phase assemblage and hydration kinetics [PDF](#)

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Five calcium sulfoaluminate (CSA) cement blends were prepared with a substitution degree of 20 wt.% of limestone (LS) and metakaolin (MK) corresponding to MK/(MK+LS) ratios of 0, 0.25, 0.5, 0.75, and 1. The hydrate phase assemblage, hydration kinetics, and the compressive strength were measured and compared to values for a pure CSA cement blend. Both metakaolin and limestone were observed to react and differences in the AFm solid solution were observed between the blends. The incorporation of metakaolin and limestone furthermore accelerated the overall hydration of the CSA cement, though the reaction of belite was retarded by the addition of metakaolin. The compressive strength increased upon addition of SCMs and the addition of both limestone and metakaolin shows great promise as potential supplementary cementitious materials in CSA cement systems at the studied replacement level of 20 wt.%.

Ultra-fast calcium aluminate cements as a way to reduce environmental footprint of Portland cement rich formulations [PDF](#)

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In applications where high performance (fast drying, rapid setting and hardening, shrinkage compensation...) is required at early age, Portland cement is accelerated by an ettringitic accelerator. The environmental footprint of these formulations can be reduced by optimizing the reactivity of ettringitic precursors and then by reducing the total binder content. In a first part, the intrinsic dissolution rate of various model ettringitic precursors are compared. In a second part, the ettringitic yield and the mechanical performances of commercial ettringitic precursors are evaluated in mortar: Calcium Aluminate Cement, Calcium Sulphoaluminate Cement and Ultra-Fast Calcium Aluminate Cement. Using Ultra-Fast Calcium Aluminate Cement allows reducing the total binder content from 25% to 15% while keeping the same level of performance than with usual Calcium Aluminate Cement or Calcium Sulphoaluminate Cement. Thanks to this, the CO₂ emissions are reduced by 40 % in the final application.

Water-to-cement ratio influence on low-carbon cements performances [PDF](#)

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Portland Cement (PC) is the most important active ingredient in most of the construction concrete. However, the PC production is associated with a high carbon dioxide release (around 1 ton of CO₂ per ton of PC). One approach to reduce CO₂ emissions consists on the reformulation of the clinker with less calcite demanding phases, such as, belite rich clinkers. The drawback of this kind of clinkers is the low reactivity of belite (beta-belite). To compensate this problem, belite rich clinkers can be prepared with ye'elimite and ferrite or with alite [known as belite-ye'elimite-ferrite (BYF) and belite-alite-ye'elimite (BAY), respectively]. In addition, it can be improved by using a high reactive belite polymorph, such as alpha-belite.

In this work, the hydration and mechanical behaviour of BYF and BAY cements (with beta and/or alpha-belite) with different water-to-cement ratios have been studied. The clinkers were produced using natural raw materials and were mixed with anhydrite (CaSO₄) to prepare the corresponding cements. At early ages, the main hydration products of these cements were ettringite, calcium monosulfoaluminate and amorphous aluminium hydroxide. At later ages, stratlingite, katoite and amorphous C-S-H were found. The compressive strength values of the corresponding mortars were correlated with the mineralogy evolution of the pastes (mainly obtained by XRD and TGA).

Manufacturing equivalent clinker by indirect mechanosynthesis process [PDF](#)

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This study is focused to the proposition of new cement manufacturing process. It is widely known that the cement production is responsible for a significant CO₂ release each year (approximatively 4 billion ton). So, it is becoming necessary to find another cement manufacturing process with a minimum CO₂ emission.

The aim of this work is to manufacture equivalent clinker by indirect mechanosynthesis process. It consists to combine between mechanical activation of the raw materials (mixture of limestone and clay) and heat treatment less than 900 °C.

The equivalent clinker obtained by this method shows the presence of the alite (tricalcium silicate) C₃S and belite (dicalcium silicate) C₂S and Tricalcium aluminate C₃A. CO₂ emission by this technique is estimated by 0.3 Ton for 1 Ton of equivalent clinker.

Reproducibility of new low clinker concrete from the laboratory scale to the concrete plant [PDF](#)

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Robustness, high early mechanical strength, initial workability and workability retention are some of the main factors required for the introduction of new low clinker cements in the market. However, high clinker replacement leads to low early mechanical strength, which one may try to be compensated with activators, but these may exhibit competitive adsorption with other admixtures. Industrial field tests, needed to verify the suitability of such binders, are expensive, time-consuming and characterised by challenging mixing conditions in real scale. Less complex and more rapid alternatives are required. To establish a correlation, we compared rheological and compressive strength measurements of a commercial cement and newly developed binder containing 50% of SCMs, in the laboratory and in the concrete plant. We show that there is a correlation for both the workability retention and the compressive strength, while the initial fluidity of the new binder is higher in the concrete plant.

Effects of superplasticizers and polymers on the hydration product morphology of sulfoaluminate cement

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Calcium sulfoaluminate (CSA) cement is widely used in architecture engineering and emergency repairs. The properties of CSA is highly depended on Ettringite (AFt), which is the main hydration product of CSA cement. AFt is an unstable phase, it will decompose to monosulfate hydrate (AFm). Stability and morphology of AFt with and without four different superplasticizers or two different polymers were investigated in this study. Thermogravimetric analysis, X-ray diffraction, scanning electron microscopy, and X-ray photoelectron spectroscopy were used for analysis. The stability of AFt increased when naphthalene sulfonate superplasticizer was used, whereas the stability decreased when the three other superplasticizers were applied. The stability further increased because of the morphology of the formed AFt crystals. In addition, certain chemical reactions occurred between AFt and the superplasticizers, particularly the polycarboxylic acid. Some calcium complex chelate compounds were also produced, and the hydration products obtained with polycarboxylic acid and naphthalene sulfonate were more compact and stable than those obtained with the two other superplasticizers. Ethylene-vinyl acetate (EVA) copolymer is useful in improving the flexural strength of CSA cement. Methylcellulose can promote the formation of AFt. The formation of AFt was relatively slow after the addition of methylcellulose in the beginning of the 30 min hydration, and methylcellulose demonstrated excellent dispersing performance, which cause AFt to crystallize well and to be uniformly distributed.

Influence of reduced CO₂ emission clinker production process on superplasticizer interactions [PDF](#)

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During the built up phase of a new kiln line of a plant with 100 % usage of alternative fuels two clinkers were selected to study the influence of the firing conditions by optimization of process engineering parameters on cement superplasticizer interactions. On laboratory cements based on these clinkers with controlled fines and SO₃ content it could be shown, that the traditional Norm-mortar testing could not resolve any changes of the resulting cements regarding workability. By the usage of Non-Norm-Mortar testing significant differences in the performance of superplasticizer were observed. Beside the performance also significant changes on development of pore solution and phase composition during the hydration occur. These differences could be correlated to the complex coupled reactions between aluminates and sulfate bearing phases. In this particular case these differences could be minimized by a new class of polymer.

Passivation of ordinary black steel reinforcement embedded in BYF mortars: effect of water-to-cement ratio, fly ash and chlorides [PDF](#)

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BYF clinkers (composed of Belite, Yeelimite and Ferrite) are promising low carbon intensity clinkers. The possibility of using ordinary black steel as reinforcement of future BYF concrete was investigated at laboratory scale, with different mix-designs of mortar (varying values of water-to-cement ratio, presence of fly ash, presence of chlorides). Without chloride, steel embedded in the different BYF mortar samples actually passivated. In comparison to Portland cement, it took longer time to achieve effective passivation with BYF. This difference is probably due to the pH below 11 with BYF at very early age before reaching a value superior to 13, allowing steel passivation. In presence of chloride, effective steel passivation was possible only if the ratio water-to-cement ratio lower than 0.5 and with less than or equal to 0.4% of equivalent chloride by weight of cement.

ORAL PRESENTATIONS
Carbonation / CO₂ Curing

Capacity for CO₂ mineralization of natural and industrial alkaline solids ^[PDF]

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Accelerated CO₂ mineralization processes rely on carbonate precipitation reactions using CO₂-rich streams (e.g., flue gas from coal-fired power plants) and alkaline solids having distinct reactivities. Assessments of carbonation potentials may be significantly affected by the process conditions implemented; thus, a consistent method of evaluating capacities for CO₂ uptake of the solid reactants is needed. In this study, the potentials for CO₂ mineralization of a suite of naturally occurring (mafic and ultramafic rocks) and industrially derived (fly ashes and slags) alkaline solids were examined. We studied 17 distinct solids having wide-ranging chemical and mineralogical compositions. The extent of formation of carbonates in CO₂-saturated water, i.e., the carbonation potential, directly correlated with the total CaO and MgO and varied inversely with SiO₂ content. This study provides a framework that can be extended to assess the efficiency of carbonation processes utilizing various solid precursors, such as in concrete, thus creating a CO₂ upcycling pathway.

Elucidating how air-filled porosity controls CO₂ uptake and carbonation strengthening in portlandite-based cementing systems ^[PDF]

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Innovative binders based on portlandite (Ca(OH)₂) compositions have the potential to take up carbon dioxide (CO₂), and form calcium carbonate compounds which offer cementitious attributes. But, carbonation processing of such materials requires elaboration of how complex pore networks, and water saturation therein affect CO₂ transport and uptake. Therefore, this paper elucidates how the creation of air-filled porosity regulates CO₂ mineralization and carbonation strengthening in portlandite-enriched cementing formulations. In general, more air-filled porosity promotes CO₂ mineralization so long as a critical liquid water saturation is exceeded; below which carbonation is sharply hindered. It is also shown that the extent of carbonation is correlated with porosity refinement and strengthening vis-à-vis uncarbonated systems. An unprecedented level of strengthening – of $\geq 3.5\times$ – is achieved for dry-cast (carbonated) portlandite mortars. The outcomes offer new insights for utilizing in situ CO₂ mineralization as a means for designing novel carbonate-based cementing agents for construction applications.

Properties of Solidia cement and concrete

[\[PDF\]](#)

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Solidia Cement containing non-hydraulic phases is produced in existing cement kilns using same raw materials as Portland cement (PC). The key difference is that this type of cement is produced using less limestone and at lower kiln burning temperatures. This translates to reduced CO₂ emissions during cement manufacturing (30% reduction). The concrete production process involves mixing cement, aggregates, sand, and water. The wet concrete is then exposed to gaseous CO₂, which reacts with the cement to form a durable matrix. The curing process can capture up to 300 kg of CO₂ per tonne of cement used. Together, Solidia Cement and Concrete production reduce the CO₂ footprint by 70% when compared to conventional cement and concrete products.

The Solid Life project (granted by EU under the LIFE program) intends to demonstrate the CO₂ and energy savings that can be realized in industrial applications and to increase the robustness of the technology. Moreover, a dedicated part of the project was to develop underpinning data for a European Assessment Document (EAD) to enable a European Technical Approval (ETA) and hence a potential route to CE marking for this new cement. To this end, concrete specimens produced by the project partners and pavers produced by commercial concrete manufacturers have been tested internally by the industrial partners and by the Building Research Establishment in terms of their durability.

This paper describes the knowledge acquired on the production of Solidia Cement to its use in precast plants and early durability results obtained from concrete specimens. Short- and long-term experiments were performed to assess the behaviour of this new type of concrete.

Accelerated carbonation of Portland cement and thermal process residues for low-carbon concrete

[\[PDF\]](#)

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The ancient Romans may have unwittingly employed accelerated carbonation with the polishing technique they used to achieve seamless crack-free linings in lime-bound pipes and stucco. However, it was not until the advent of Portland cement in the mid-19th century that carbonation with gaseous CO₂ at atmospheric pressure was proposed as a means of accelerating the setting and hardening of mortar and concrete. In the 1970s the first attempts were made to achieve a more thorough scientific understanding of the process, and the authors' own development of a carbonation process to accelerate the hardening of precast concrete dates from over 30 years ago, before reduction of CO₂ emissions was as pressing a concern as it is today. This paper reports on current research and commercial operations involving accelerated carbonation of Portland cement and concrete and of thermal process residues, while looking forward to challenges and opportunities in a low-carbon future.

Revealing the microstructure evolution and carbonation hardening mechanism of β -C₂S pastes by backscattered electron

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β -dicalcium silicate (β -C₂S) minerals were prepared. The carbonation products composition, microstructure and distribution of hardened β -C₂S paste were revealed by X-ray diffraction (XRD), Fourier transform-infrared (FT-IR) and Backscattered electron (BSE) image analysis. The results show that a dense hardened paste of β -C₂S can be obtained after 24 hours carbonation curing. The hardened pastes are composed of pores, silica gel, calcium carbonate and unreacted dicalcium silicate, with relative volume fractions of 1.3%, 42.1%, 44.9% and 11.7%, respectively. The unreacted dicalcium silicate is encapsulated with a silica gel rim, and the pores between the original dicalcium silicate particles are filled with calcium carbonate. The sufficient carbonation products that rapidly formed during the carbonation curing process, forming a dense microstructure, are responsible for the carbonation hardening of the β -C₂S mineral.

Depth profiles of concrete cover during natural carbonation

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This paper presents a field test and experimental investigation on the depth profiles of concrete cover during natural carbonation. A 77-year-old steel mill was inspected, and its column concrete cover samples were analysed by the phenolphthalein test, the expression method, X-ray diffraction, TG, SEM and MIP.

The in-situ test results indicate that the rebar embedded in concrete had begun to corrode when the carbonation depth was almost less than one-third of the cover depth. The corrosion initiation of the rebar started from the corrosion of the ribs because the carbonation front is always the first to reach the surface of the rib. And the existence of semi-carbonation zone in concrete is the cause of this phenomenon. The initiation corrosion of rebars embedded in concrete can occur when the pH values was in the range of 11.3–12.1.

Three areas of carbonation were determined using the pore solution pH and concentration of CaCO₃ and Ca(OH)₂. The pore solution pH test results and XRD analysis indicate that there is a semi-carbonated zone between the full-carbonated zone and the uncarbonated zone in the corrosion process induced by carbonation. The pH value of the full-carbonated zone has a pH of 8.0–9.5, and almost no Ca(OH)₂ is in the concrete cover. The pH value of the semi-carbonated zone is in a range of 9.5–12.1, and the concrete cover contains both Ca(OH)₂ and CaCO₃.

Based on the carbonation mechanism of concrete, a theoretical mathematical model of carbonation reaction and its numerical solution method were established. Based on the semi-carbonation zone defined in this paper, the effect of water-cement ratio, cement dosage, relative humidity, carbonation time and carbon dioxide concentration on the length of the semi-carbonation zone was analysed. A theoretical model of the length of the semi-carbonation zone was established.

ORAL PRESENTATIONS

Durability

How to combine CO₂-performance with service life durability parameters of concrete [PDF](#)

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The challenge concrete construction will be facing in the future is to achieve the lowest possible CO₂ intensity over the entire life cycle. It is therefore essential to further increase the clinker efficiency and to reduce the CO₂ intensity of concrete. Concrete constituents are to evaluate and use according to their availability and performance. Apart from mechanical properties (e. g. compressive strength) also robust fresh concrete properties (workability, sedimentation stability) suitable in building practice are important and when it comes to assessing the application of an exterior component also durability has to be considered. To evaluate concretes in this regard, compressive strength and durability performance/service life should be related to CO₂ intensity. It is shown how durability testing and calculations are to be used to combine CO₂ performance with service life durability parameters of concrete and to achieve the lowest possible CO₂ intensity taking into account the availability of materials.

Durability and sustainability implications of concrete reinforced with aluminium metal [PDF](#)

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Aluminium metal cannot be used to reinforce regular concrete since the high pH will attack it and evolve hydrogen gas. However, aluminium metal alloyed with 5% magnesium is stable in concrete when 55% cement is replaced with calcined clay in the concrete mix. Replacing high fraction of clinker with clay calcined at 850 °C gives obvious savings in energy and CO₂ emissions. Since aluminium can withstand carbonation and chlorides, only 20 mm cover for mechanical anchoring of reinforcement is required and a smaller volume of concrete is needed. The binder with 55% calcined clay is sulphate resistant, and no chance of AAR is expected due to lower pH and no remaining calcium hydroxide in the system. Hence, the only degradation mechanism left is freeze-thaw action that can be avoided by air entrainment. Thus, in theory an infinite service life without maintenance may be at hand for aluminium metal reinforced concrete.

The challenge of determining carbonation resistance of modern concretes

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A critical threat to concrete is CO₂, which is now present in the atmosphere at record concentrations. Increasing presence of CO₂ in the atmosphere makes concrete structures more vulnerable to degradation due to carbonation; this problem is coupled with the increase in use of concrete mixtures that contain high-volume supplementary cementitious materials (SCMs) that are even more vulnerable.

The relatively low concentration of CO₂ in the atmosphere (0.03 – 0.04%) makes carbonation a slow process in dense and chemically stable cementitious materials. This has led to the development of accelerated testing methods exposing the material to high CO₂ concentrations to induce carbonation. This is usually achieved using climatic chambers where the exposure conditions such as temperature, relative humidity (RH) and concentration of CO₂ can be completely controlled. However, it is object of significant discussion how meaningful the results obtained from accelerated carbonation test are, as there is a high variability of accelerated carbonation testing conditions specified in the limited number of standards for evaluation this property. The reproducibility and repeatability of the results obtained by following different accelerated carbonation testing protocols has also been strongly questioned.

To elucidate best practices for determining carbonation resistance of modern concretes the RILEM technical committee (TC) 281-CCC 'Carbonation Resistance of Concrete with SCMs' is evaluating the existing methodologies for assess carbonation under accelerated conditions. A critical overview of those standards is presented, and factors that will influence performance of modern concretes during testing are highlighted. The combination of varying testing conditions and difficulty in obtaining reproducible results makes extremely difficult to draw correlation among studies adopting different carbonation testing protocols using conventional approaches to evaluate this phenomenon.

Passivation behaviour of mild steel in the pore solution of magnesium phosphate cement

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Magnesium phosphate cement (MPC) is one of a variety of novel cements being considered by the construction industry as an alternative to Portland cement (PC). Due to its rapid-setting and excellent adhesion properties, it has gained popularity as an effective repair material for concrete structures. However, currently MPC is only accepted in niche applications. The wider application of MKPC is restricted mainly due to a lack of understanding of its interaction with other materials – in particular, steel reinforcement. Compared with PC, the unique chemistry of MPC causes a significant reduction of pH which could affect the passivation behaviour of steel.

In this study, the passivation behaviour of steel reinforcement (i.e. rebar) in extracted MPC pore solution formulated with different magnesium-to-phosphate (M/P) ratios, namely 5, 7, 12 and 17, was investigated using a range of characterisation techniques. Electrochemical methods, including linear polarization resistance (LPR), Open Circuit Potential (OCP) and electrochemical impedance spectroscopy (EIS), were implemented to gain an understanding of the passivation behaviour of embedded steel rebar both kinetically and thermodynamically. X-ray photoelectron spectroscopy (XPS) and Raman spectroscopy were also used to characterise the chemical composition of the passive film formed.

Results show that, despite the low pH of MPC pore solution, a protective layer, which is similar to the passive film formed in PC on the surface of rebar, has been identified on the steel surface immersed in all the MPC pore solutions. However, different from the passive film formed in the PC system, the passivity of the rebar in MPC could be formed from the precipitation (M/P 5 and 7) or

adsorption (M/P 12 and 17) of PO₄³⁻ dissolved in the MPC pore solution on the surface of rebar. In addition, it was found that the degree of passivity also increases with the M/P molar ratio, which is probably due to the increasing pH of the pore solution.

Evaluation of the sulfate attack resistivity of cement-based materials modified with nanosilica

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The addition of nanoSiO₂ greatly affects the physiochemical properties of hardened cement-based materials. In this work, the modification effect of nanoSiO₂ on the sulfate attack resistivity of hardened cementitious materials was investigated. Its effects on the corrosion resistivity were evaluated through compressive strength measurement and its comparison with those of other common supplementary cementitious materials (SCMs). Effectiveness and efficiency of nanoSiO₂ on sulfate attack resistivity of cementitious materials were calculated and evaluated. Factors governing the sulfate attack resistance performance of nanoSiO₂ and SCMs-modified cementitious materials were discussed.

Durability and sustainability consideration for structural use of reactive MgO cement

[PDF](#)

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Reactive-MgO cement (RMC) is an emerging material with a potential to be a long-term sustainable alternative to ordinary Portland cement (OPC) due to its capability to sequester CO₂ under carbonation-based strength development. Synthesis, reactivity, microstructural and mechanical properties and recyclability of the material have been the focus of many other recent studies. This study assesses the carbonation process of RMC and corrosion resistance of embedded low-carbon reinforcing rebar with mechanical, leached-pore solution pH, chemical, microstructural and electrochemical tests. The results showed that the RMC-paste specimens exposed to accelerated carbonation under 20% CO₂ attained similar strength to that of OPC of the same water-binder ratio. Potential CO₂ sequestration at maturity was estimated to be 5% of MgO weight. However, a low pH of the pore solution had an adverse effect on corrosion performance of the embedded rebar which exhibited poor passivity and corrosion resistance under 3.5% NaCl exposure.

Temperature – a key factor for the physical sulfate attack

[PDF](#)

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In this study, the influence of temperature on the extent of physical sulfate attack (PSA) on mortar samples was investigated. Mortars, made with water to cementitious ratios between 0.4 and 0.6, were subjected to cycles of immersion at different temperature (5, 20 °C) with 5% (w/w) sodium sulfate solution and drying at 50 °C. The assessment criteria were based on visual appearance and mass loss. The results show that the damage is more severe at 20 °C than at 5 °C, and the decay patterns are different at different temperatures: fine crumbling at 5 °C; corner scaling at 20 °C. Furthermore, the adverse effects of higher water to binder ratio on the resistance of mortars to PSA were captured.

Frost resistance of coal gangue aggregate concrete modified by steel fibre and slag powder

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for the application of coal gangue aggregate concrete in cold regions.

Coal mining and washing process will produce a large number of solid waste coal gangue, which have a serious impact on the environment, and using recovered coal gangue as a light aggregate to mix concrete can reduce the impact to a certain extent.

Considering the excellent properties of fibre reinforced concrete in resisting external forces and high durability, as well as the pozzolanic effect and secondary hydration of mineral admixtures, which can save cement and improve durability and strength when used in concrete, this study attempt to modified the coal gangue aggregate concrete with steel fibres and slag powder, and studied its frost resistance, including the mass loss, loss of relative dynamic elastic modulus, compressive strength loss and the splitting tensile strength loss after freezing-thawing. The effects of steel fibre type and substitution rate of slag powder on air-void characteristics of coal gangue aggregate concrete were also analysed.

The results show that the frost resistance of coal gangue aggregate concrete will be significantly improved by incorporating appropriate amount of steel fibre, and the undulated steel fibre has obvious advantages in reducing the strength loss of coal gangue aggregate concrete after freezing-thawing; the mechanical properties and frost resistance of coal gangue aggregate concrete can be significantly reduced by incorporating slag powder as admixture instead of cement, and the effect is more obvious with the increase of substitution rate of slag powder. Mixing with the hooked-end steel fibre can optimize the internal structure of coal gangue aggregate concrete, and make the air-void of concrete tends to be smaller, which is beneficial to its frost resistance. The research results can provide theoretical basis and technical support

Advances in chloride ion diffusion coefficient test research for concrete

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Chloride ion diffusion coefficient has important significance for evaluation of the ability to resist chloride ion penetration for concrete and prediction of the durability for concrete structure within chloride salt environment. Based on critical literature review, chloride ion diffusion coefficient tests are classified according to their basic theories. Comparison is carried out from the view of different dimensions such as accuracy of theory, practical difficulty, data collection difficulty, test standing time, application scope etc. So far, chloride ion diffusion coefficient tests are all adopting Fick's law or Nernst-Planck equation which is the extension of Fick's law. Steady state diffusion test, unsteady state diffusion test and steady state migration test have high accuracy of theory. Surface steady state migration test and water saturated conductivity test are suitable for in situ determination. It is necessary to conduct a unified study for enhancing and standardizing relevant standards.

Effect of activators on the passivation of steel reinforcement in alkali-activated slag

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The passivation process of steel reinforcements is commonly occurred when they are embedded in concrete. This process promotes the formation of a dense and protective oxidation layer (i.e. passive film) on the surface of reinforcements which can prevent the steel from corrosion. However, the formation of this stable passive film requires a high pH environment (usually above pH 9.4), which is often maintained by the $\text{Ca}(\text{OH})_2$ and other alkalis dissolved in the PC pore solution, leading to a pH environment higher than 13. Nevertheless, not only the high pH can enhance the protectiveness of the passive film, some anions (e.g. NO_3^{2-} , CO_3^{2-} , SiO_3^{2-} and S^{2-}) can also significantly change the nature of the passive film formed. Due to the different cement chemistry involved in alkali-activated slag, in particular, different activators used, such as NaOH (pH>13), Na_2SiO_3 (silicate salt, pH>13), Na_2CO_3 (weakly alkaline salt, pH~11.5) and Na_2SO_4 (neutral salt, pH~7), it is expected that both the passivation process and the passive film formed in AAS systems could be different from that of the PC. Although the knowledge on the passivation of steel is essential for the industrial application of reinforced AAS concretes, surprisingly, the relevant studies reported in the literature is very limited. Therefore, the purpose of this study is to investigate the effect of different types of activators on the passivation behavior of steel reinforcement in AAS.

To simulate the possible environment that the steel reinforcements might be exposed to in AAS concretes, the extracted AAS paste pore solutions were used in this study. Four activators, namely, NaOH, Na_2SiO_3 , Na_2CO_3 and Na_2SO_4 , were used to formulate AAS pastes. The alkali concentration of all the activators were fixed at 5% Na_2O equivalent by the weight of slag. The water-to-slag ratio was also fixed at 0.5 for both AAS and PC control. In addition, for the Na_2SiO_3 activated slag, the silica modulus was fixed at 1.2. Passivation processes were monitored in a tailor-

designed electrochemical cell by using Electrochemical Impedance Spectroscopy (EIS), Linear Polarisation Resistance (LPR) and Mott-schotky (M-S) analysis. The morphology of the stable passive film was also characterised by Scanning Electron Microscopy (SEM).

The results show that some distinct differences in the steel passivation can be identified between the PC and AAS systems. The passivation behaviour in PC is highly dependent on the pH and the protective ability of passive film in PC could be mainly attributed to its high charge transfer resistance which inhibits the transport of electrons from the steel to the pore solution. On the contrary, the passivation processes in AAS were more complex due to the presence of sulphide ions (originated from the slag) and different anions from the activators. In particular, the competitive adsorption onto the steel surface was observed between the OH^- and $\text{HS}^-/\text{S}^{2-}$ ions which could be attributed to the stronger polarizability of HS^- ions. Thus, it is expected that a Fe-S/Fe-S-O layer could be formed on the steel surface in AAS systems, instead of the normal Fe-O layer formed in the PC system. As the existence of S^{2-} in the passive film may weaken its charge transfer resistance, the protectiveness of the passive film could, therefore, be weakened. On the other hand, since different anions were introduced into the AAS systems by different activators, it is expected the anions may also play a role in the formation of the passive film. Among the four activators, SiO_3^{2-} and CO_3^{2-} ions seems to be able to enhance the passive film, which can partly offset the negative influence of sulphide. However, the SO_4^{2-} ions seem to have a negative effect, resulting in an unstable passive film and pitting corrosion. Overall, the quality of the passive films formed could have an order of $\text{Na}_2\text{SiO}_3 > \text{PC control} > \text{Na}_2\text{CO}_3 > \text{NaOH} > \text{Na}_2\text{SO}_4$. Nonetheless, despite the negative effect of sulphide on the formation of passive film, the presence of S^{2-} ions may have a positive effect on the corrosion resistance of rebar in AAS. This is because the sulphide ions in the pore solution can generate a reducing environment, leading to the inhabitation of steel corrosion.

ORAL PRESENTATIONS

Emerging Technologies

The effect of cellulose nanocrystals (CNCs) on the properties of cement paste

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The influence of cellulose nanocrystals (CNCs) on the properties of cement pastes is studied. The mechanical properties of CNCs/cement paste was investigated under the defined curing system ($20 \pm 2^\circ\text{C}$ and $95 \pm 5\%$ for 7d, then $4 \pm 2^\circ\text{C}$ and the $55 \pm 5\%$ for 21d.). Furthermore, the 2D micrographs and 3D defects distribution have been characterised by scanning electron microscopy (SEM) and X-ray computed tomography (XCT) respectively. But most surprising, it was found that CNCs could improve the mechanical properties of hardened cement pastes tremendously under the curing system when rapid decrease of temperature and humidity happens, the compressive strength of the cement paste with 0.5% CNCs by weight of cement could reach 21.6MPa, compared with the cement paste without CNCs is 0MPa. The optimization of 2D/3D microstructure by CNCs could be the principal reason for the improved performance of the hardened cement pastes with CNCs. It could be safely concluded that CNCs plays an excellent effect in preventing hardened cement pastes from cracking, and CNCs will have a broad application prospects in concrete construction at relatively lower temperature (above zero degree) environment.

Characterisation of the passivation process of mild steel with in-situ Raman Spectroscopy

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The passive film formed on the surface of steel reinforcement in high alkaline environment of concrete, usually with a pH around 13, performs as a protective layer in preventing the further corrosion of steel. A good understanding of the passive film is thus essential for improving the durability of reinforced concrete. Although electrochemical measurements are well-established for detecting the passivation process, the information obtained is generally indirect and can be affected by many environmental factors like humidity and temperature. Most importantly, the chemical compounds formed in the passive film, which is the key information needed to assess the quality of the passive film, are often missing in the electrochemical measurements. In the past, several microscopic methods, such as scanning tunnelling microscope (STM), electron diffraction (ED) and X-ray absorption near-edge spectroscopy (XANES), have been employed to investigate the passivation process, which, however, all suffer from their incapability in distinguishing between Fe_3O_4 and $\gamma\text{-Fe}_2\text{O}_3$. Raman spectroscopy is thus employed in this work to characterise the passivation process, thanks to its high chemical fingerprint sensitivity to all possible compositions of passive film.

In this work, an in-situ Raman spectrometer was employed to study the passivation process of mild steel in simulated concrete pore solution. The dynamic evolution of the compounds formed within the passive film was directly monitored. A tailored-designed device was employed so that both the Raman spectroscopy and the electrochemical measurements can be carried out simultaneously. In this study, the electrochemical measurement was performed by a Gill AC instrument (ACM) to confirm the formation of the passive film on the surface of

reinforcement, which was then used to verify the results obtained from Raman spectroscopy.

The Raman spectra obtained between 0 and 6 hours showed that the main peak was located at $\sim 674 \text{ cm}^{-1}$ which was associated with the symmetric stretch vibration of oxygen atoms along the Fe-O bonds in T sites of Fe_3O_4 . Additionally, the intensity of the peak increases with time, indicating the constant formation of Fe_3O_4 during the first 6 hours. The electrochemical measurements result also confirmed the passivation process, where OCP and LPR measurements exhibit reproductive behaviour, characterized by the rapid increase in the potential and resistance respectively during the first 6 hours, indicating a constant growth of the passive film. Furthermore, the EIS measurement reveals an overall rise of the resistance of the system, further confirming the occurrence of the passivation process. Therefore, the in-situ Raman spectroscopy is proved to be capable for effectively monitoring the evolution of the passivation process. Moreover, using this tailor-designed in situ Raman system, the formation of the passive film in simulated PC pore solution has been identified as dominated by a constant growth of Fe_3O_4 on the surface of mild steel.

Effect of nano alumina on compressive strength and porosity of high-volume slag pastes [PDF](#)

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This paper presents the effect of nano alumina (NA) on compressive strength and porosity of cement pastes containing high volume blast furnace slag (BFS) contents of 70%, 80% and 90% by weight. NA and BFS are used as partial replacement of cement, and all mixes contain same water-to-binder ratio. Results show that the addition of NA improves the compressive strength of high volume BFS pastes. However, only at 70% BFS content the compressive strength exceeds the control cement paste. However, in the paste containing 80% BFS and NA the compressive strength is only 2% lower than control. The addition of NA significantly reduced the volume of large capillary pores of high volume BFS pastes. However, mixed results are obtained in the case of medium capillary and gel pores. While the addition of high volume BFS shifted the concentration of pore sizes from large to medium capillary pores in cement paste, no such improvement is observed due to the addition of NA in high volume BFS pastes.

The evolution of microstructure of cement paste during early hydration in the presence of cationic asphalt emulsion [PDF](#)

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As a kind of organic-inorganic composite, cement-asphalt (CA) paste could be considered as the cement paste modified by asphalt emulsion. While, the formation and evolution of microstructure of CA paste during early hydration period has attracted interest due to which is correlated well with the properties of CA paste, including the workability, strength and durability. Therefore, the purpose of the study is to disclose the process of cement hydration and the evolution of microstructure in the presence of cationic asphalt emulsion. The retardation effect of cationic asphalt emulsion on cement hydration was validated by the results of setting time, hydration heat, conductivity, Fourier transform infrared spectroscopy (FTIR) and X-ray computed tomography (X-CT). In addition, the retardation mechanisms of cement hydration were proposed, and the coverage of asphalt film on the surface of cement was observed by Field emission scanning electron microscopy (FESEM).

Influence of highly dispersed nano-SiO₂ on the early age hydration of cement paste [PDF](#)

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Nano-SiO₂ particles have been widely used in cementitious materials recently. However, the poor dispersion of nano-SiO₂ in cement paste remains a big challenge. In this study, highly dispersed nano-SiO₂@PCE particles with core-shell structure were synthesized by surface modification. Comparative studies on the cement hydration rate, microstructure development, early age properties were carried out between the modified nano-SiO₂@PCE particles and unmodified nano-SiO₂ particles. The results of isothermal calorimetry test show that the peak of hydration heat flow curve is increased intensively even with only 0.5 percent by mass of the addition of nano-SiO₂@PCE, which can be explained by the seeding effect. The better dispersed nano-SiO₂@PCE provides more seeding sites for hydration products. Compared with the unmodified nano-SiO₂, nano-SiO₂@PCE particles enhance the micromechanical properties of early hardened cement paste, which could be attributed to their higher pozzolanic activity and their positive influence on the pore structure.

Mechanical property of ecological high ductility cementitious composites for bridge deck link slab under variable temperature conditions [PDF](#)

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Ecological High Ductility Cementitious Composites (Eco-HDCC) has a promising application in bridge deck link slab. Temperature difference is obvious due to climate conditions for various regions. To explore effect of variable temperature conditions on the structural design of bridge deck link slab made by Eco-HDCC, compressive property and flexural property were studied. The specimens were exposed to -30 °C, 0 °C, 20 °C, 40 °C and 60 °C condition, and maintained for 4h. In addition, mercury intrusion porosimetry test was carried out to analyze the pore structure after different temperature treatment. Results indicate that compares to property of Eco-HDCC specimen at room temperature (20 °C), the compressive strength and flexural strength decrease after exposed to -30 °C and 0 °C, while strength show an increasing trend after 40 °C and 60 °C treatment. In addition, flexural deflection increases after different temperature treatment. Moreover, the porosity of Eco-HDCC specimen will be uniform exposed to variable temperature.

Upcycling carbon dioxide to improve mechanical strength of Ca(OH)₂ based binder system with PVA [PDF](#)

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The production of ordinary Portland cement is a highly CO₂-intensive process. To ease the environmental burden, there is an urgent requirement for securing alternatives to Portland cement. Ca(OH)₂ (CH) based binder system is one of the potential options. This study demonstrates a new pathway for CH-based cementation by the introduction of PVA. The effect of a series of PVA with different molecular on the mechanical property of CH-based binder were investigated. The results show PVA present different influences before and after the carbonation of CH-based binder. PVA-2 exhibit the best efficient performance under CO₂ uptake process.

Bond behaviour of basalt FRP bars in geopolymer concrete [PDF](#)

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Geopolymer concrete (GPC), an environmentally friendly alternative to ordinary Portland cement concrete, reinforced with basalt fibre reinforced polymer (BFRP) bars, a corrosion resistant substitute to steel bars, is a novel, durable and sustainable composite for construction. This study aims to promote its utilisation by investigating the bond behaviour which is accepted as the most critical factor assuring the composite action of the structural reinforced concrete members. The bond behaviour of 6-, 8- and 10-mm nominal diameter BFRP bars in 150-mm GPC cubes was explored by conducting a direct pull-out test. Three embedment lengths (5db, 10db, and 15db) were adopted in order to analyse the interface bond between the BFRP bars and the GPC. The results showed that as the diameter and the embedment length increases, the bond strength decreases.

Matrix superhydrophobic foam cement via physical and chemical modification of interfaces [PDF](#)

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Porous structure will bring many durability problems to foam cement as water becomes a medium of transmission. A novel superhydrophobic cement foam was fabricated by simultaneously physical and chemical modifications of air-liquid interfaces. Firstly, the modified nano-silica after grafting water repellent functional group onto the surface will absorb onto the gas-liquid interfaces and increase the viscosity of cement suspension, preventing the fusion and disproportionation of bubbles. Secondly, the liquid film forming by calcium stearate combining with the water-repellent functional group pulling the nano-silica toward gas phase, a multi-scale roughness was created successfully. The coupled effect of the physical and chemical interfacial modification results a bulk superhydrophobic cement foam which will help porous cement-based materials owning better durability in future.

Void spacing factor characterization via X-ray CT from aspects of void-void proximity and paste-void proximity [\[PDF\]](#)

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The air void as part of pore structure in cement based materials plays an important role in determination of the resistance to the freeze-thaw attack. It is of essential importance to describe the air void system and quantitatively determine the primary related parameters: total void content, specific surface, and spacing factors. Compared with content and size distribution, the spacing factor is considered to be the best index to reflect the quality of the void system and evaluate the durability of the concrete to freezing-thawing. In this study, based on the reconstructed microstructure obtained on X-ray CT technique, the void spacing factor was defined and calculated from the aspects of void-void proximity and paste-void proximity. The random points and count-dilation method were applied to calculate the paste-void proximity. Further, the results were compared with the Lu and Torquato's equation to verify its reliability.

Effects of plastic expansion agent on the mechanical and deformation properties of concrete [\[PDF\]](#)

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The shrinkage of concrete is one of the primary reasons causing the debonding of concrete filled steel tubes (CFST). This paper had achieved a goal of non-shrinkage of CFST at plastic stage through the usage of a kind of plastic expansion. The effects of water-binder ratio, the dosage of plastic expansion agent and the setting time on the mechanical properties, plastic deformation and pore structure of CFST were investigated. The results show that the appropriate dosage of plastic expansion agent is 0.02%-0.04% and the CFSTs take a micro-expansion tendency at plastic stage. What's more, there is no remarkable harmful effect on mechanical properties of hardened concrete. The expansion mechanism of plastic expansion agent was analysed from the aspects of internal resistance and pore structure.

Effects of expansive materials on cracking resistance of sprayed concrete [PDF](#)

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Sprayed concrete always presents the defects that will damage the bearing capacity and durability of lining concrete, such as the large early shrinkage, poor toughness and low crack resistance. In consideration of the early age expansive performance and promoting cement hydration of expansive materials, deformation performance, mechanical properties and microstructures of sprayed concrete with expansive materials were investigated. The relation between expansive properties and cracking resistance of sprayed concrete were discussed. The results show that expansive agent can shorten the setting time of cement pastes with liquid setting accelerators. Setting accelerators increased the autogenous shrinkage significantly and increased by more than 200µε on 7d. With the addition of expansive agent at 4wt% addition, the autogenous volume deformation reduced substantially but the sprayed concrete with liquid setting accelerator still be the shrinking state. The compressive strength of sprayed concrete with expansive agent increased especially for the concrete with alkali-free setting accelerator.

Corrosion behaviour of low-carbon steel in alkali-activated slag mortar under simulated marine environment [PDF](#)

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This research concerns the passivation behaviour and corrosion resistance of low-carbon steel (20MnSiV) in ordinary Portland cement (PC), alkali-activated slag (GGBS-W) as well as alkali-activated slag & steel slag (SS-W) mortars under simulated marine environment. Compared with OPC mortar, less passive film was formed at passivation stage but when the specimens were exposed to 3.5 wt. % NaCl solution it presented higher corrosion resistance in both AAS and AASS groups. This was mainly attributed to compact microstructure and protective hydration products in alkali activated mortars.

Passivation behaviour of steel rebar in Portland cement pore solution under microwave curing

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Steam curing has been widely employed as an accelerated curing method in precast concrete industry to speed up the manufacture process. However, its high energy consumption has increasingly become a concern. As a promising alternative, microwave curing method can significantly reduce the energy consumption at an even faster curing speed. However, the possible effects that the electromagnetic field of microwave may have on the formation of the passive film of steel reinforcements in concrete is unknown, causing concerns over the durability performance of reinforced concrete cured by microwave.

This paper, thus, reports a study on the passivity of steel rebar in Portland cement pore solution under microwave curing. The behaviour of the rebar was also compared with those cured under simulated steam curing. Three electrochemical methods, namely, linear polarization resistance (LPR), Open Circuit Potential (OCP) and electrochemical impedance spectroscopy (EIS), were adopted to assess the passivation behaviour of the rebar under different curing conditions. The morphology and microstructure of the steel surface were also characterised by scanning electron microscopy (SEM) and atomic force microscopy (AFM).

The results show that the initial passivity of the steel rebar immediately after the 8-hour microwave curing was slightly better than that of the stimulated steam curing. However, during the subsequent room temperature curing, the degree of the passivity of the steam cured rebar increased at a faster rate than that of the microwave cured rebar, and after 7 days room temperature curing, similar passivity was obtained regardless of the curing techniques applied. On the other hand, similar roughness and thickness of the passive film were identified from AFM and SEM, which are around 60nm and 20nm, respectively. Moreover, the kinetics study of the passivation process also suggests that the initial

passivation reaction rate can be further enhanced under microwave curing, which could be attributed to the reduced diffusion activation energy of the passivation process by the accelerated motion of charged ions under microwave.

Sulfate resistance of cement paste exposed to sodium sulfate solution by X-ray computed tomography

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X-ray computed tomography (X-ray CT) method is proposed to in situ monitoring the damage process of cement paste containing different water-to-cement ratio (0.55, 0.40) exposed to sodium sulfate solution. In addition, the corrosion products were analyzed by X-ray diffraction (XRD). The results show that X-ray CT can track the time-dependent development of cement paste exposed to sodium sulfate solution. Furthermore, the information of cracks spatial distribution, gray values, corrosion depth and pore volume distribution can be clearly obtained by this method.

Preparation of high strength lightweight concrete with vibration mixing technology

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The preparation processes of high strength lightweight concrete (HSLC) have raised great concerns in recent years. Although the traditional roller mixing equipment has been deemed as a feasible way to mix ingredients of concrete, the current studies find that workability and hardened properties of HSLC are still limited by machine itself. For the purpose of improving properties in HSLC, a new method of vibration mixing technology, which means vibration while mixing and dispersing raw material, was applied in this research. The slump, compressive strength with various water to binder (w/b) ratio were tested to evaluate efficiency of vibration mixing technology. Simultaneously, the distribution of lightweight coarse aggregates in hardened concrete, thermo-gravimetric analysis (TGA) technology and scanning electron microscope (SEM) are used to compare the difference of vibration and non-vibration mixing process. The test results indicated that the slump prepared with vibration mixing process is higher 15-20 mm than that of non-vibration mixing process in the case of w/b ratio ranging from 0.32 to 0.40. The 28d cubic compressive strength increased 2.4 and 3.9 MPa at w/b ratio of 0.28 and 0.32, respectively. It can be attributed to the decrease of thickness of interface transition zone (ITZ), and the increase of hydration degree due to application of vibration mixing technology. It is concluded that the vibration mixing process is an effective way to develop HSLC.

ORAL PRESENTATIONS

Magnesium Based Systems

New insights into the hydration of cementitious materials based on magnesium carbonates [PDF](#)

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The hydration of reactive periclase (MgO) in the presence of hydromagnesite ($\text{Mg}_5(\text{CO}_3)_4(\text{OH})_2 \cdot 4\text{H}_2\text{O}$) was investigated by a variety of physical and chemical techniques. This system is of potential interest as low CO_2 binder, if the magnesium carbonate is produced by carbonation from naturally occurring magnesium silicates such as olivine or serpentine.

In contrary to thermodynamic prediction not artinite ($\text{Mg}_2(\text{CO}_3)(\text{OH})_2 \cdot 3\text{H}_2\text{O}$), but a very poorly-crystalline form of brucite ($\text{Mg}(\text{OH})_2$), and an unknown amorphous hydrate which partially loses its crystal water at about 100 °C were the main hydration products.

Preparation and mechanical properties of ultra-high strength magnesium phosphate cement composites [PDF](#)

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Based on the unique properties of magnesium phosphate cements, this paper aims to investigate the potential for producing ultra-high strength magnesium phosphate cement composites (UHMPCC). The results show that the UHMPCC of 28-day compressive strength in the range of 140-165 MPa can be prepared using common materials and preparation methods. The bond between steel fiber and UHMPCC matrix and mechanical properties were improved by adding a certain amount of ultra-fine fly ash. Significant enhancements in mechanical strength of UHMPCC were observed when 2% steel fibres were used. The compressive strength and flexural properties of UHMPCC were superior to those of traditional ultra-high-performance cement composite having the consistent cementitious matrix-strength.

Factors influencing the mechanical properties of reactive magnesia concrete under accelerated carbonation [PDF](#)

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This study investigated the factors influencing the mechanical properties of reactive MgO cement-based concrete formulations by varying the water and air-entrained agent contents. Samples were subjected to accelerated carbonation under 10% CO₂ for up to 28 days. Their mechanical performance and associated formation of carbonation phases were analysed by compressive strength testing and x-ray diffraction analysis. The porosity, influenced by the water content, was key in the determination of the final mechanical performance. Lower water contents led to higher strengths. Introduction of air-entrained agent decreased the early-age strength due to the increased air content in the prepared formulations. This was compensated by improved CO₂ diffusion, carbonation and strength gain in reactive MgO blends in the longer periods.

Ultrafine fly ash modified bischofite-based basic magnesium sulfate cement [PDF](#)

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A novel "one-pot process" was proposed for preparation of basic magnesium sulfate (MOS-517) cement with high compressive strength by using diluted H₂SO₄ as both activator of fly ash and reactant in the reaction with reactive magnesia (90%, fabricated by a pyrolyzation of bischofite). The ultrafine fly ash (α-UFA) activated by 20% H₂SO₄ exhibited a porous surface with a high specific area of 48 m²/g, which is in favor of improving the interfacial compatibility between UFA particles and 517 phase. The amorphous silica in α-UFA particles could react with MgO/Mg(OH)₂ and water to form stable magnesium silicate hydrate at weakly alkaline condition (pH 9.5~10.5). Moreover, the dissolved Al³⁺ ions might substitute Mg²⁺ ions during the hydration process to form a finer porous structure. As a result, the compressive strength of MOS-517 cement with 20% α-UFA reached 67.0 MPa (28 d), highlighting its potential application in the construction industry.

Sustainable calcination of magnesium hydroxide for the production of magnesium oxychloride cements [PDF](#)

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Effects of varying calcination conditions on the chemical and physical properties of magnesium oxide (MgO) were investigated using magnesium hydroxide (Mg(OH)₂). Extremely pure and thus more reactive MgO was obtained using a 17.6% less energy intensive calcination regime compared to industrial grade MgO obtained from the calcination of dolomitic lime. As a result, the magnesium oxychloride (MOC) cement that was produced from the sustainably sourced MgO obtained a 50% increase in flexural strength and a 22% increase in compressive strength. This was mostly due to its homogenous microstructure consisting predominantly of the phase-5 hydration product. Based on these findings, it has been revealed that the calcination therapies currently used in industry are impractical for both economic and sustainability purposes; MgO can be manufactured in a more sustainable and thus, more competitive means, as discovered in this study.

Effects of temperature history on expansion properties of CaO- and MgO-bearing expansive agent for concrete [PDF](#)

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Aiming at the problem that a single type of expansive agent often cannot effectively compensate the shrinkage deformation of concrete at different stages, CaO- and MgO-bearing expansive agent was designed and prepared. Effects of curing temperature on expansion behaviours of mortars with CaO- and MgO-bearing expansive agents were investigated. The expansion behaviour of compound expansive agents in concrete based on environment simulation test chamber were analysed. And applications of the materials in practical engineering were introduced. The results showed that curing temperature has a great influence on the expansion performance of CaO- and MgO-bearing expansive agent in concrete. CaO- and MgO-bearing expansive agent is suitable for compensating the shrinkage of mass concrete with high temperature rise and slow temperature fall. According to actual temperature history of concrete, selecting proper activity of MgO and the ratio of CaO and MgO can realize the whole process control of compensating concrete shrinkage.

Chloride ion penetration resistance and pore structure of magnesium silicate hydrate (M-S-H) mortars [PDF](#)

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The main purpose of this paper is to study the chloride ion penetration resistance and pore structure of magnesium silicate hydrate cement (MSH) mortars. The chloride ion penetration resistance of MSH mortars with different water-to-cement ratios (0.5, 0.55, 0.6) and different sand rates (25%, 50%, 75%) was studied and compared to ordinary Portland cement (OPC) mortars. The pore structure of magnesium silicate hydrate mortar was tested using mercury intrusion porosimetry (MIP). The results indicate that the chloride ion diffusion coefficient becomes larger with an increase in the water-to-cement ratio and sand rate; the coefficient of MSH mortars is much smaller than that of OPC mortars. The results of MIP show that MSH mortars generally have gel pores measuring less than 10nm; however, the pore size of OPC mortars is dominated by pores measuring 10nm to 100nm. Finally, MSH mortars were found to be less porous than OPC mortars.

ORAL PRESENTATIONS

Waste Utilisation

Changes in particle morphology and property of recycled fine aggregates modified by microbial carbonate precipitation [PDF](#)

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This paper reports the study on particle morphology and property of recycled fine aggregates (RFA) modified by microbial carbonate precipitation (MCP) employing *Sporosarcina pasteurii* (*S. pasteurii*). Two parameters, Ellipse ratio and solidity, are selected to describe the macroscopic and mesoscopic particle morphology of the aggregate respectively. The results show the change of particle morphology parameters before and after modification is insignificant. On this basis, the water absorption of modified RFA and the mortar cast by modified RFA are experimentally tested. The results show the change of water absorption of RFA and mortar before and after modification are 25.7% and 25.6% respectively. This paper shows that the use of MCP to modify RFA does not change the particle morphology at the macroscopic and mesoscopic levels. However, the water absorption of modified RFA and the mortar cast by modified RFA are reduced.

The dissolution behaviour of lithium slag in alkaline and acid leaching process [PDF](#)

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This study aims to advance the understanding of the dissolution behavior and mechanism of Lithium Slag (LS) in the alkali activation process. Two different kinds of activator solutions were used to evaluate the effects of the agitation speed, leaching agent concentration and leaching agent types on the LS leaching process. The elemental analysis of dissolved materials was determined by inductively coupled plasma-optical emission spectrometry (ICP-OES), and the dissolution rate of all soluble elements in LS was used to describe the solubility of LS in the leaching process. It was found that the greatest effect was observed on leaching agent concentration and leaching agent types.

Arsenic speciation and pH-dependent leaching from cement paste from industrial waste co-processing [PDF](#)

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Co-processing of industrial wastes as alternative raw materials in the cement kiln is resource efficient, but can result in enrichment of toxic metals, including arsenic (As), in cement and products made from it that are then dispersed in the built environment. Accordingly, this study aims to understand the speciation and pH-dependent leaching of As from cement paste made with clinker from co-processing of lead/zinc smelter slag or air pollution control residue (APCR) from municipal solid waste combustion, in comparison with the wastes and paste made by blending of the wastes at ambient temperature. The results show that pH-dependent leaching of As is similar in the co-processed paste, as in the original waste and blended pastes. X-ray absorption spectroscopy suggests that arsenic is present in all samples as a poorly crystalline arsenate phase, but qualitative geochemical modelling suggests that As solubility may be controlled by secondary surface complexation to iron oxides.

Low-CO₂ binders for restoring a Pb-contaminated soil: Improvements and drawbacks with respect to ordinary Portland cement [PDF](#)

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The remediation of heavy metal contaminated soils is usually approached with binder-based techniques, like solidification/stabilization (S/S), and ordinary Portland cement (OPC) as the main binding agent. This paper reports our preliminary attempts of substituting traditional OPC with more environmentally sustainable alkali-activated cements, in the S/S of a Pb-contaminated soil. The treatment of Pb contamination is complicated by the amphoteric behaviour of Pb, whose mobility is increased at high pH values, which are characteristic of cementitious systems. The use of alkali-activated cements proved to be suitable for soil remediation, with different performances depending on the formulation studied. These preliminary findings may be further enhanced by long-term investigations and further optimization of the alkaline activating solution, as first steps towards the improvement of the environmental impact of soil remediation technologies.

3D X Ray micro-tomography as a tool to formulate metakaolin-based geopolymer-oil emulsions [\[PDF\]](#)

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Composite materials made of geopolymer (GP) cement and organic liquids are useful to synthesize porosity-controlled media, for the management of radioactive organic liquid waste, or as phase change materials (PCM). Indeed, GP cements are able to integrate huge amounts of organic oils by direct emulsion in the fresh paste. The emulsion (GEOIL) remains stable during GP hardening.

In this contribution, by using 3D X Ray micro Computed Tomography (micro CT) with a voxel size of 1 micron³, we investigate the effect of formulation parameters (oil proportion, Si/Al molar ratio, surfactant) on the 3D oil droplet structure of GEOIL pastes. Samples are emulsified in the fresh state and imaged in the hardened state. Porosity, oil droplet size distribution and mean distance between droplets are all determined quantitatively.

It is observed that the presence of surfactant provides significantly smaller oil droplets. The increase in Si/Al ratio also decreases the oil droplet sizes, but to a lesser extent.

Effects of ceramic powder on cement hydration and compressive strength of concrete [\[PDF\]](#)

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In this research, ceramic powder was taken as a supplementary cementing material to replace cement partly. The effects of ceramic powder on compressive strength and hydration properties were researched. Eight groups of cement-based materials were designed with a fixed w/b ratio 0.4, including 5 groups of mortar mixed with ceramic powder, with a cement substitution rate of 0%, 10%, 20%, 30%, 40% respectively; 3 groups of cement paste mixed with ceramic powder, with a cement substitution rate of 0%, 20%, 40% respectively. First, the compressive strength of mortars was assessed by means of mechanical test at curing ages of 7 days to 90 days. Then, the chemical composition of hydrated blended pastes was carried out using X-ray diffraction (XRD) analysis and thermogravimetry (TG) measurement, respectively. The obtained results show that: (1) mortars with an amount of up to 30 mass% cement replacement by ceramic powder possess better mechanical performance, although they have minor strength loss at early age; (2) the Ca(OH)₂ content was found to decrease with time for ceramic-powder cement pastes which provides the evidence of the pozzolanic activity of ceramic powder.

Influence of pozzolanic activity of clay brick powder on properties of mortar

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The properties of clay brick powder (CBP) and mortar were tested to investigate the influence of fineness of CBP on the properties of mortar. The results show that with increase of fineness of CBP, the specific area increases and surface binding energy decreases, which indicates the pozzolanic activity of CBP is enhanced by increasing fineness. The early hydration is accelerated by increasing the fineness of CBP, and the compressive strength of mortar with 30% CBP is 10%~35% lower than mortar without CBP, and the higher the fineness of CBP, the faster the compressive strength grows. The X-Ray diffraction (XRD) results also prove that the CBP with higher fineness will consume more $\text{Ca}(\text{OH})_2$. It could be concluded that the pozzolanic activity of CBP would be enhanced with the increase of fineness.

Hydration properties of Portland cement-tuff powder composite

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Tibet of China is rich in water resources, but it lacks mineral admixtures such as fly ash to build roller compacted concrete (RCC) dams. To save construction costs, local tuff is ground and used as a substitute material for fly ash to prepare RCC. Through compressive strength, X-ray diffraction (XRD), thermogravimetry-differential thermal analysis (TG-DTA), and scanning electron microscope (SEM) analysis, the hydration and compressive strength development of cement-tuff composite system were investigated in this study.

The results show that tuff powder has certain pozzolanic activity, which can replace fly ash as a mineral admixture to reduce both the early hydration rate and the cumulative hydration heat released from the hydration. Furthermore, thermal curing was found to be able to accelerate the pozzolanic reaction of tuff powder. Additionally, the alkaline matter in tuff powder can also promote the early hydration of this composite system to improve its early compressive strength. Although, in general, higher fineness can enhance the chemical reaction, it was found in this study that grinding the tuff powder to a specific surface area of $590 \text{ m}^2/\text{kg}$ is sufficient for the RCC application. Continuous grinding above $590 \text{ m}^2/\text{kg}$ seems to have little effects on the compressive strength development, even though the costs will increase.

Application of AFm-like layered double hydroxide in the purification of environmental pollutants

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AFm phases are major hydration products of Portland cement pastes. The structure of AFm phase can be assembled by layered double hydroxides. It has the general formula $[M^{2+}_{1-x}M^{3+}_x(OH)_2]^{x+}[(A^n-)_{x/n}]_mH_2O$, in which $M^{2+} = Ca^{2+}, Mg^{2+}, Ni^{2+}, Cu^{2+}, Zn^{2+}, Co^{2+}$, etc. and $M^{3+} = Al^{3+}, Fe^{3+}, Cr^{3+}$, etc; A^n- is an anion, such as $CO_3^{2-}, SO_4^{2-}, NO_3^-, Cl^-, OH^-$ and even an organic anions. AFm-like LDHs have attracted considerable attention for their potential use as adsorbents and ion exchangers. For this report, we will review main progresses of our team in the purification and remediation of environmental pollutants using controlled formation process of AFm-like LDHs in real waste water systems. For example, Ca/Al-Cl LDH was used for the treatment of stabilized landfill leachate. It was found that Ca/Al-Cl LDH can efficiently remove organic matters such as fulvic acid-like and humic acid-like compounds in the leachate. Furthermore, real electroplating waste water containing CrO_4^{2-}/Zn^{2+} ions was effectively purified via the formation of ZnAl-Cr LDH.

Recycled carbon fibre composite modification and its effect on the performance of cement-based materials

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The waste management of carbon fiber polymer composites has serious environmental implications if the wastes are sent to landfill or incineration. Proper chemical treatment of recycled carbon fiber composites (RCFC) has been demonstrated to potentially add value to them, by improving the performance of cementitious materials incorporating them. This laboratory investigation explored the viable chemical treatment for RCFC that contained residual cured epoxy on its surface, and evaluated the effects of alkali-treated RCFC on the mechanical property and volume stability of cementitious mortar. A total of thirteen mortar mixtures were designed, considered the untreated RCFC, RCFC treated by 1, 2 and 3 mol/L NaOH solution, RCFC treated by SPS for different time periods followed by triisopropanolamine (TIPA), or RCFC treated by montmorillonite nanoclay emulsion (mNCE, at the nanoclay dosage of 0.75% by weight of cementitious binder), respectively. The dosage of RCF was 1% volume and the water-to-binder ratio was 0.50. The compressive strength, splitting tensile strength and free drying shrinkage of RCFC reinforced mortar were evaluated. The results show that the residue epoxy resin on the surface of the RCFC was removed by the immersion in NaOH solution or SPS, but a long-time treatment may result in damage of the fiber surface. The chemical treatment of RCFC showed both mechanical and chemical benefits to its adhesion with the cementitious mortar. Admixing mNCE achieved outstanding strengths of the mortar similar to those of mortars treated by SPS for 0.5 h and then TIPA. The scanning electron microscopy revealed that the treated RCFC had better adhesion to the mortar matrix than the untreated one.

Early hydration of dry-mix sprayed concrete [PDF](#)

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With the use of a special cement, so called 'spray-binder', dry mix shotcrete can be applied without extra accelerators, such as aluminium sulphate based products used for wet mix shotcrete. The hydration reactions of the spray-binders differ from those of these latter systems among others due to the low sulphate content in the spray-binders. The need to substitute clinker by hydraulic or inert filler materials to increase durability and sustainability is becoming also urgent in the case of shotcrete. In this paper we present data from calorimetry, TG and XRD on the hydration of pure spray-binder and in combination with limestone, slag and metakaolin. The results, in combination with real scale spraying early strength tests, show that limestone can moderately accelerate the early hydration of these systems, whereas substitution of spray binder by slag and/or metakaolin leads to lower early strength.

Using oil shales for production of low-carbon Portland cement [PDF](#)

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Oil shales with low organic content can be potentially used for the production of Portland cement. The presence of oil in them can significantly reduce the consumption of fuel in clinker production. In addition, oil shale added to the kiln feed reduce the temperature of clinkerization. In this study, Israeli oil shales with low organic content were investigated as a raw material for kiln feed in the production of cement. It was found, that Israeli oil shale can replace up to 76% of the typical raw materials in the production of belite-rich cement. The clinkerization temperature required to obtain the necessary compounds was 1250 °C. The resulting clinker was analysed with respect to the mineral composition, density, and hydration rate. The results of the current research indicate that the use of oil shale for cement production may result in significant energy saving and reduction of carbon dioxide emissions.

From waste to structures: Mechanical and durability properties of bottom ash concrete [PDF](#)

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Current societal waste production has reached an alarming peak. The incineration of non-hazardous non-recyclable waste (namely municipal solid waste) can be a viable solution. The generated bottom ash is a potential material to be used in concrete as partial cement replacement. This has the double advantage of reducing landfill and at the same time reducing the cement content in concrete (largely responsible of the concrete carbon footprint). Using ground bottom ash as supplementary cementitious material is a potential option for valorisation. This paper presents mechanical and durability properties of concrete with bottom ash as partial cement replacement in comparison to two reference concrete mixes. Mechanical properties were affected by the use of bottom ash, however at a similar level as expected from ordinary coal combustion fly ash. Durability properties were preserved with 25 % of bottom ash replacement. This encourages further research to optimize the use of otherwise-landfilled-material as possible cement replacement in concrete.

Experimental study of slag gypsum cement concrete to recycle waste gypsum board [PDF](#)

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Waste gypsum board has increased by more than 1 million tons in Japan. However, the recycle system of the waste gypsum board is not progressed yet and no standard is enacted in Japan. Long time has passed after the study of Slag Gypsum Cement (SGC) was implemented in which the gypsum was generally supplied from the gas discharged from Oil/Coal-fired power plant. It is not sure whether the waste gypsum treated from the waste gypsum board is appropriate for the replacement of the flue gas desulfurization gypsum. For this reason, it is needed to investigate the fundamental properties of SGC concrete for the effective use of the waste gypsum board. This research has shown that the SGC concrete provided high resistance against the sulfuric attack but on the other hand low resistance against freeze-thaw attack.

Review of rapid assessment of fly ash reactivity for low-carbon concrete manufacture [PDF](#)

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Pozzolanic materials such as fly ash, contribute to savings of Portland cement in concrete and hence lower its carbon footprint. Recent reductions in coal-based energy generation have led to attention being given to the use of stockpile fly ash and imported material, whose activity needs to be assessed on a batch basis and within pressing time-frames. The literature indicates that attempts have been made to correlate some properties of fly ash with strength development of the resulting mortar or concrete. Other research has focussed on test methods involving accelerated reactions with Portland cement, lime or alkalis, measuring heat evolution, aqueous concentrations or conductivity changes. This paper reviews the available test options and comments on their advantages / limitations as research / industry tools, supported with our own laboratory results, covering a wide range of fly ashes, where appropriate. The methods considered include material characterisation (PSD, XRD, XRF, FTIR), rapid assessment tests (Frattini, Chapelle, conduction calorimetry, etc.) and traditional activity index mortar tests.

Enhancement of the environmentally friendly features of belite-calcium sulfoaluminate cements through the use of industrial by-products [PDF](#)

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In this work, the possibility of using titanogypsum (T) and water potabilization sludges (WPS) as a source of material in the production of belite calcium sulfoaluminate (BCSA) cements has been investigated. Four BCSA clinker-generating raw mixes were heated in a laboratory electric furnace in the temperatures range 1200 -1350 °C: one included only natural materials (limestone, clay, bauxite and gypsum); the others contained T and/or WPS as total substitute for natural gypsum and clay, respectively.

Quantitative X-ray diffraction analysis on the burning products showed high conversion of reactants toward the main BCSA hydraulically active clinker components (C2S and C4A3\$), especially at 1300 or 1350 °C. Moreover, isothermal calorimetric measurements associated with differential thermal-thermogravimetric analyses showed that all BCSA cements, obtained by adding commercial anhydrite to the clinkers produced at the optimum synthesis temperatures, generally displayed a similar hydration behaviour.

POSTER PRESENTATIONS

Physical properties of cement pastes with different wood biomass ash contents [PDF](#)

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The European Union plans a complete shutdown of coal power plants by 2030. It consequently leads towards significant increase of wood biomass usage as renewable energy source, hence increase of wood biomass ash (WBA) amount. Landfilling expenses and lack of new landfills set of the need for reuse of WBA. Partial replacement of cement could be one of the possible solutions for WBA use in the concrete industry. Lack of regulations and standards for WBA usage in cement mixtures, as there are for coal fly ash, emphasize the need to determine the potential of WBA use as a cement replacement. The properties of WBA vary depending on the type of used wood biomass, combustion technology and location of the ash collection. This paper is focused on the effect of using WBA in different contents on the physical properties of cement composites (workability, setting time and soundness).

Influence of inhibitor addition method to the reinforcement corrosion of coral aggregate seawater concrete [PDF](#)

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To improve the durability of coral aggregate seawater concrete (CASC) structures, linear polarisation resistance method (LPR) and electrochemical impedance spectroscopy method (EIS) are used to calculate the electrochemical parameters such as self-corrosion potential (E_{corr}), polarisation resistance (R_p) and charge transfer resistance (R_{ct}). The influence of inhibitor addition method on the corrosion performance of steel in CASC are investigated, and the corrosion deterioration law of steel in CASC is obtained. It shows that: Either traditional addition and pre-absorption with amino alcohols inhibitor (AA), the corrosion resistance of steel has been improved to varying degrees, and pre-absorption of AA is better than traditional addition in improving the corrosion resistance of steel. For CASC structure in marine engineering, it was suggested adopting pre-absorbed 2%AA, which could prolong the initial stage of reinforcement corrosion, reduce the corrosion rate and prolong the service life of the structure.

Effect of a novel nanomaterial on chloride transport in cement-based materials [PDF](#)

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The corrosion of steel in concrete will make our infrastructures rapidly deteriorating, the maintenance and rebuilding will consume a large quantitatively number of cement and steel, so it's meaningful to improve the resistance of concrete to chloride ingress for a green low-carbon world. This study examines the effect of a novel nanomaterial on chloride transport and microstructure of cement-based materials. The chloride diffusion coefficient was reduced from $11.44 \times 10^{-12} \text{m}^2/\text{s}$ to $7.13 \times 10^{-12} \text{m}^2/\text{s}$ when 0.9% nanomaterial was added in concrete, the compressive strength was slightly increased from 49.34 MPa to 50.04 MPa. Several methods were used to characterize cement paste microstructure, MIP results show that pore porosity was changed and XRD results indicate Calcium hydroxide was decreased, this nanomaterial can react with calcium ions. This kind of nanomaterials can promote the durability of reinforced concrete.

A new recycling method using demolished concrete and by-products for the purpose of minimizing the environmental load [PDF](#)

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This report provides a technical proposal of a new recycling method using the demolished concrete debris and industrial by-products (coal ash, blast furnace slag) with the purpose of minimizing the environmental load. The quality of demolished concrete is the quality by merely crushing the concrete by a jaw crusher, etc. And the technical proposal provides the application method for the low-grade concrete (rubble concrete) with a compressive strength of several N/mm² while enabling the effective use of industrial by-products. This report also provides a technical proposal on the method of manufacturing concrete using a truck agitator within a construction side. These technical proposals in an actual site allowed not only the manufacture and use of concrete satisfying the target quality, but also the realization of recycling of approximately 11,500 tons of demolished concrete debris and significant reduction of the environmental load.

Effects of water-cement ratio and aging on the solar reflectance of cement paste [PDF](#)

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High solar reflectance endows material with keeping its surface cool in the sun without utility of electricity. Both top coatings and substrates can alter the shape of reflectance spectrum, changing the cooling efficiency of the whole system. Most current passive cooling designs focus on the top painting but ignore the contributions from substrates. The factors affecting solar spectral properties of cement, the most widely used building materials, were systematically investigated in this article. A UV-Vis-NIR spectrophotometer equipped with a 150 mm diameter integrating sphere was used to measure the spectral reflectance of white- and grey-cement paste surface from 250 nm to 2500 nm. The reflectance of pastes generally grew as water-cement ratio increased and hydration reaction progressed. Titanium dioxide and cenospheres were added to improve the reflectance of the substrate. A simple indoor temperature test showed that the surface made of white-cement paste kept 15 °C lower than grey-cement surface.

Design research for diaphragm-connected anchor tooth-block anchorage zone of UHPC box-girder [PDF](#)

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To obtain the local action effect, the bearing capacity and tensile failure mode of the diaphragm-connected anchor tooth-block in the UHPC continuous box-girder, the finite element parameter analysis of the tooth-block anchorage zone was carried out by ABAQUS and a full-scale prestressed tensile experiment of the UHPC segmental box-girder was carried out, taking a newly built UHPC continuous bridge as the engineering background. The conclusions were as follows: Six kinds of local action effects of the diaphragm-connected anchor tooth-block anchorage zone were revealed. The diaphragm-connected anchor tooth-block had greater advantages than conventional independent anchor tooth-block. Increasing the diaphragm width was more beneficial to the mechanical property of the anchorage zone. In the background engineering, when the maximum tensile load reached 4700kN, the visible cracks could not be found and the measured strain value had not exceed the visible initial crack strain of UHPC in the experimental box-girder. Although UHPC in anchorage zone had entered strain hardening stage in the process of prestressing, the structure was still in normal use. The strain hardening platform stage of UHPC should be fully utilized in design.

Influence of functional components on the durability of concrete structure in marine area [PDF](#)

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This study aims to solve the longstanding durability issues regarding chloride ion corrosion of concrete structures. The electrochemical methods were used to investigate the anticorrosion performance of the migrating corrosion inhibitor (MCI-0). After adding the anticorrosion component to the concrete, both crack and corrosion resistance qualities showed a great enhancement. The test results indicate that the migrating corrosion inhibitor has satisfactory electrical and chemical performance, and the polarization potential of the reinforced bar maintained stable when at least 2% of the inhibitor was added to the concrete. The mechanical and resistance performance of the concrete was effectively improved when the electric flux was less than 1000 if 15% of the compound functional components were added.

Freeze-thaw damage mechanism of Cao-Na₂CO₃-slag cement mortar [PDF](#)

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Freeze-thaw resistance was studied on mortars prepared with alkali-slag cement by using CaO+Na₂CO₃ as the activator. Two mortars based on alkali-slag cement with strength of 35 MPa (CNS35) and 50 MPa (CNS50), and one based on ordinary Portland cement with strength of 35 MPa (PC35) were prepared. Damage coefficient of relative dynamic elasticity modulus, flexural strength and paste matrix micro hardness were applied to assess the Freeze-thaw durability of mortar. Meanwhile, microstructure and performance mechanism were analysed through MIP, XRD and SEM-EDS. Results showed that the ability of freeze-thaw resistance of mortar were: CNS50 > CNS35 > PC35. The CNS35 mortar has better initial pore structure compared with PC35 mortar. SEM and micro hardness analysis revealed that the CNS mortar has no obvious ITZ and the hydration products of CNS mortar were denser compared with PC mortar. The main hydration products of CNS mortar were C-S-H (I) gel with low Ca/Si ratio. The initial pore structure, the density of cement stone and ITZ of CNS50 mortar were better than that of CNS35 mortar.

Monitoring of corrosion stress of reinforced concrete under accelerated corrosion by innovation methods [PDF](#)

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The corrosion process of concrete reinforced by two kinds of steel bars (one is Q235 carbon steel bar and the other is corrosion-resistant steel bar) under accelerated corrosion is tracked in real time by using X-ray computed tomography (XCT). The displacement and strain fields of XY plane at different depths of corroding reinforced concrete were calculated by using digital image correlation (DIC) technology. It turned out that the crack location and the whole process of reinforced concrete corrosion could be directly reflected by the images collected by XCT, and the inner strain evolution in anywhere could also be calculated quantitatively by DIC. The corrosion stress applied on steel bar and concrete could be calculated according to the inner strain and Young's modulus. The non-uniform corrosion of steel bar and induced compressive or tension stress in different places of concrete could be observed on reinforced concrete under accelerated corrosion. When concrete mixed with seawater under constant potentiostatic accelerated corrosion, the corrosion delay effect of corrosion resistance steel bar was not obvious.

Influence of key parameters in CSA mix proportion on properties of CSA-CI system

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Calcium Sulfoaluminate Cement (CSA) has good chloride binding capacity and has potential to reduce risk of reinforcement corrosion once marine aggregate is used. The binding capacity of CSA is sensitive to its mix proportion and needs to be clearly studied. In this paper, influence of water to powder ratio (W/P) and use of gypsum on the properties of CSA cement are reported and it can be concluded that compared with samples with a W/P of 0.4, those with 0.5 had a slower setting process, a higher compressive strength and a better chloride binding capacity; gypsum slowed down the setting process, led to an decrease in contents of aluminate hydrates and Friedel's salt, and an increase in ettringite, which caused a severe drop in chloride binding capacity; chloride ions accelerated the setting process, decreased the amount of heat generated, but its effect on compressive strength at 28 day was less significant.

Possibilities to reduce CO₂ emissions with efficient binders [PDF](#)

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In the search for reduction of carbon dioxide emissions in the production of hydraulic binders, numerous works concentrate on the replacement of Portland cement clinker with alternative cementitious binders. However, when substituting the cement clinker not only the possible CO₂ reduction must be considered. Rather, the alternative cementitious binder should show a comparable performance as the substituted product. There is no point in producing a cement with a good carbon footprint if an increased binder content in the concrete is needed to meet the required properties.

Although Portland cement clinker initially appears very unfavourable in terms of CO₂ emissions, alternative low-carbon binders often cannot achieve the performance of Portland clinker-based binders. The increase in low-carbon binder content resulting in the required performance often negates its better CO₂ balance.

It will be shown how to optimise binders based on Portland cement clinker in terms of CO₂ efficiency. To assess the performance, the 2 and 28-day compressive strengths are used. To achieve the 28-day compressive strength targets, a reduction from 750 to 200 CO₂ per ton of cement is possible, and even the required 2-day early strength can be achieved with Portland clinker-based cements with CO₂ emissions of 550 kg/t. This corresponds to a reduction in CO₂ emissions of more than 70 % or 25 %, respectively. By reducing the clinker content, carbon capture and storage will in turn become more cost-effective.

Cost accounting, which ultimately drives the optimisation of cement production, shows which cements are most suitable for their intended use in terms of their CO₂ efficiency.

Alkali activated mortars formulation optimized by an experimental design [PDF](#)

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The worksites of "Grand-Paris" will generate high amounts of excavated lands, without few recovery routes. One of them could be to use those excavated lands into alkali activated materials, based on ground granulated blast furnace slag. The study herein presented concerns the feasibility of using various untreated soils originating from Normandy (France) as the granular skeleton in alkaline activated granulated blast furnace slag-based mortars. The use of experimental designs allowed to optimize the binding phase, by varying the composition of the activation solution, for sand and slag-based mortars. The impact of hardened properties of materials was thus studied.

Development of mathematical models for predicting the hydration process using the EIS impedance of high-belite calcium sulfoaluminate cement

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High belite calcium sulfoaluminate cement has a wide application potential due to its low energy consumption, low CO₂ emission and excellent durability performance. In this study, the early age hydration process of high belite calcium sulfoaluminate cement paste is characterized using the rate of change in impedance measured by electrochemical impedance spectroscopy (EIS). In the belite calcium sulfoaluminate cement system, hydrated products are mainly comprised by calcium aluminate hydrate (Aft, AFm, C₄AH₁₃, C₃AH₆, etc.) and gel phase (AH₃, C-A-S-H, C-S-H). For cement-based systems with large gel phase content, there are some limitations for the traditional hydration kinetics test method such as calorimetry test, chemical shrinkage test and chemical bound water content test. By applying the electrochemical impedance spectroscopy (EIS) test method, the limitations of traditional hydration testing methods can be overcome. Therefore, the mathematical equation between EIS test method and traditional hydration test method can be established to improve the evaluation the hydration degree model of cementitious materials, which the hydration degree model from

$$\alpha = \frac{W_n(t)}{W_n^0} = \frac{H(t)}{H^0} = \frac{CS(t)}{CS^0}$$

$$\text{to } \alpha = \frac{W_n(t)}{W_n^0} = \frac{H(t)}{H^0} = \frac{CS(t)}{CS^0} = D \frac{\ln(k_1 \rho_1)}{\ln(k_2 \rho_{\text{total}})}$$

It provides theoretical and practical support for evaluation of hydration process of cementitious materials and non-destructive testing technology, also provides strong guarantee for the development of application system of new cementitious material system.

Mechanical properties of alkali activated copper slag mortars after exposure to elevated temperatures [PDF](#)

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Compressive and flexural strengths of alkali activated copper slag (AACS) mortars, with activator of NaOH at the concentrations of 6M, 8M, 10M and 12M, are studied at room temperature and after exposure to elevated temperatures of 200 °C, 400 °C, 600 °C, 800 °C, 1000 °C and 1200 °C, respectively. Evolution of chemical compositions and micro-structure of AACS with temperature was further analyzed by using their paste counterparts. The results show that the strength of AACS mortars increased dramatically within 200 °C, followed by a decline, and increased again after 800 °C. After 600 °C, Fe₂O₃ was formed as a result of the oxidation of Fe₂SiO₄ and/or the decomposition of Fe(OH)₃/Fe(OH)₂. With temperature increased further, Fe₂O₃ could have melted in a Na-rich environment to flow through the pores and cracks in the matrix. When the matters cooled down, they could have filled in the pores and cracks and then make the matrix much dense to provide high strength.

Effect of temperature rising inhibitor on expansion behaviour of cement paste containing expansive agent

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The present study aims to examine the mechanism influencing the expansion characteristics of expansive cement paste in presence of different dosages of Temperature Rising Inhibitor (TRI). The expansion of cement pastes showed a higher expansion strain of the OPC-EA mixture with 0.2% and 0.4% TRI in comparison to the reference sample and a decreased shrinkage of cement pastes containing expansive agent (OPC-EA). Meanwhile, dynamic elastic modulus, hydration kinetics, mineral phase compositions and microstructure characterization of hydration products were also investigated by ultrasonic method, isothermal calorimetry, quantitative X-ray diffraction and scanning electron microscope, respectively. The delayed hydration process of expansive agent increases the amount of expansive agent available to react after the setting of cement pastes, resulting in the increased expansion strain of OPC-EA-0.2%TRI sample. The higher expansion strain of OPC-EA-0.4%TRI sample can be attributed to the lower stiffness of cement paste affected by TRI. The results showed that the addition of TRI is the main force in delaying the hydration process of ye'elimite in expansive agent by acting on the formation and morphology of ettringite. The delayed ye'elimite hydration process can be explained by inhibition of the precipitation or/and growth of ettringite.

Additions of different calcium carbonate minerals in cement to increase material greenness [PDF](#)

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The production of ordinary Portland cement (OPC) is currently responsible for 8-9% of the global CO₂ emissions. To reduce the consumption of OPC, different mineral additives have been frequently used as the cement replacements. The carbonate systems in the nature have been creating various forms of CaCO₃ minerals, which can sustain the continuation of cement production and reserve potentials in developing new cements. Although the direct additions of limestone powder into OPC have been practiced for a few decades, there are still unknown sciences behind the engineering practices, particularly in the nano- and micro- levels for different types of CaCO₃. In our study, 3 different types of calcium carbonate minerals, namely, geological-based (limestone), biological-based (seashell) and lab-based (chemical purity CaCO₃), were used in cementitious system. The effects of the different types of CaCO₃ on the rheology, mechanical strength, hydration products and the micro-structure for the blended cements were revealed.

Potential influence of microwave heating on the thermal stability of Fe-ettringite

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Microwave heating is being increasingly recognised as a potential, alternative, low-carbon curing technique for the precast concrete industry because it can provide several benefits, including fast heating and energy saving due to its volumetric heating as well as the enhanced productivity achieved from the reduced curing duration. However, similar to other accelerated curing techniques, the highest curing temperature is still to be determined by the thermal stability of ettringite. As the ettringite formed during the hydration of Portland cement is usually doped by Fe ions, creating an Fe-ettringite, it is therefore the thermal stability of Fe-ettringite under microwave heating that determines the highest curing temperature for microwave-based curing technique. It is generally believed that the interaction of microwave radiation with matter occurs via two distinct processes, namely, thermal and non-thermal effect. The thermal effect refers to the heating generated through the dielectric interaction between material and microwave, whilst the non-thermal effect often relates to the reduced activation energy and, consequently, increased chemical reaction rate due to the unique vibration of the photons at the frequency of microwave irradiation. When microwave heating is applied in curing precast concrete, not only can it generate thermal effect, but also non-thermal effect, which may result in the modification of the structure of hydrated products. As a result, there are concerns as to whether the thermal stability of Fe-ettringite could be affected due to possible modifications of the crystal structure of Fe-ettringite by the non-thermal effect of microwaves.

In this study, Fe-ettringite, synthesised according to Struble's method, was heated using both microwave and conventional heating at 60, 70 and 80°C for 8 hours and its thermal stability was investigated.

Following the heating, Thermogravimetric Analysis (TG), X-ray diffraction (XRD), Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM), X-ray Photoelectron Spectroscopy (XPS) and Nuclear Magnetic Resonance (NMR) were used to characterise the samples.

Results show that at 60, 70 and 80°C, the decomposition temperature of microwave-heated Fe-ettringite was consistently lower than the samples subjected to conventional heating. As the temperature rose from 60 to 80°C, the calculated *ab* and *c* lattice axes of Fe-ettringite shrank more in samples subjected to microwave heating than those subjected to conventional heating at the same temperature. Moreover, increasing the temperature from 60 to 80°C damaged the microwave-heated Fe-ettringite samples much more than those conventionally heated. In addition, microwave heating reduced the binding energy of both Ca and S atoms as well as changing the chemical environment around the Al nucleus. These results indicate that the thermal stability of Fe-ettringite is reduced when subjected to microwave heating. One possible reason can be assigned to a non-thermal effect from microwave heating.

Preparation of geopolymer using electrolytic manganese residue and fly ash by alkaline activation

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As a toxic industrial waste product, electrolytic manganese residue (EMR) causes severe environmental concern. Fly ash is an industrial waste from the power plant. geopolymer is a new cementitious material, which can effectively solidify heavy metals. In this study, EMR and fly ash were investigated for utilization as a raw material for geopolymer production. Source materials were activated using water glass and NaOH of activator and cured at 60 °C. The characterization of geopolymer were performed through mechanical properties, XRD, ICP-AES and SEM in this work. The results indicated that heavy metals in EMR could be effectively solidified in geopolymer. Content of EMR had different effects on the mechanical properties of geopolymer. This work does not only prove that EMR and fly ash can be used as the raw materials for geopolymer, and it has the characteristics of large consumption of EMR, low cost and broad prospects for industrial application.
