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11th ACI/RILEM INTERNATIONAL CONFERENCE ON CEMENTITIOUS MATERIALS AND ALTERNATIVE BINDERS FOR SUSTAINABLE CONCRETE

Editor:
Arezki Tagnit-Hamou

American Concrete Institute
Always advancing

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Sponsored by
American Concrete Institute, RILEM, Université de Sherbrooke, CRIB, Université Toulouse III, Lmdc Toulouse, Kruger Biomaterials, Euclid Chemical, Prodexim International inc., BASF Master Builders, ACAA

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PREFACE

In July 1983, the Canada Centre for Mineral and Energy Technology (CANMET) of Natural Resources Canada, in association with the American Concrete Institute (ACI) and the U.S. Army Corps of Engineers, sponsored a five-day international conference at Montebello, Quebec, Canada, on the use of fly ash, silica fume, slag and other mineral by-products in concrete. The conference brought together representatives from industry, academia, and government agencies to present the latest information on these materials and to explore new areas of needed research. Since then, eight other such conferences have taken place around the world (Madrid, Trondheim, Istanbul, Milwaukee, Bangkok, Madras, Las Vegas, and Warsaw).
The 2007 Warsaw conference was the last in this series.

In 2017, due to renewed interest in alternative and sustainable binders and supplementary cementitious materials, a new series was launched by Sherbrooke University (UdeS); ACI; and the International Union of Laboratories and Experts in Construction materials, Systems, and Structures (RILEM). They, in association with a number of other organizations in Canada, the United States, and the Caribbean, sponsored the 10th ACI/RILEM International Conference on Cementitious Materials and Alternative Binders for Sustainable Concrete (ICCM2017). The conference was held in Montréal, QB, Canada, from October 2 to 4, 2017. The conference proceedings, containing 50 refereed papers from more than 33 countries, were published as ACI SP-320.

In 2021, UdeS, ACI, and RILEM, in association with Université de Toulouse and a number of other organizations in Canada, the United States, and Europe, sponsored the 11th ACI/RILEM International Conference on Cementitious Materials and Alternative Binders for Sustainable Concrete (ICCM2021). The conference was held online from June 7 to 10, 2021. The conference proceedings, containing 53 peer reviewed papers from more than 14 countries, were published as ACI SP-349.

The purpose of this international conference was to present the latest scientific and technical information in the field of supplementary cementitious materials and novel binders for use in concrete. The new aspect of this conference was to highlight advances in the field of alternative and sustainable binders and supplementary cementitious materials, which are receiving increasing attention from the research community.
To all those whose submissions could not be included in the conference proceedings, the Institute and the Conference Organizing Committee extend their appreciation for their interest and hard work.

Thanks are extended to the members of the international scientific committee to review the papers. Without their dedicated effort, the proceedings could not have been published for distribution at the conference. The cooperation of the authors in accepting reviewers' suggestions and revising their manuscripts accordingly is greatly appreciated.

The assistance of Chantal Brien at the Université de Sherbrooke is gratefully acknowledged for the administrative work associated with the conference and for processing the manuscripts, both for the ACI proceedings and the supplementary volume.

Arezki Tagnit Hamou, Editor

Chairman, eleventh ACI/RILEM International Conference on Cementitious Materials and Alternative Binders for Sustainable Concrete (ICCM2021).
Sherbrooke, Canada
2021

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EFFECT OF MINERAL ADDITIONS ON THE SELF-HEALING ABILITY OF CEMENTITIOUS MATERIALS

Carol Namnoum, Benoît Hilloulin,Maxime Robira, Frédéric Grondin, Ahmed Loukili.

Synopsis: The production of cement by calcination of limestone releases large amounts of carbon dioxide. Development of concrete quality lead to optimize the sustainability and maintenance phases of concrete structures, so, using supplementary cementitious materials (SCM) is one of the methods adapted to reduce the environmental impact of cement production. In addition, self-healing of concrete appears as a process to considerably improve the durability of a damaged structure [1]. As revealed by most analyses, mineral additions can be used to improve the autogenous healing ability of cementitious materials [2].

In this study, the influence of using a combination of SCMs, such as ground granulated blast furnace slag and metakaolin, on the mechanism of autogenous crack healing was assessed in ternary formula. Self-healing evolution was characterised by means of mechanical tests carried out on notched mortar samples with different substitution ratios. The mechanical recovery was investigated after the healing period. Moreover, the micro-chemical structure of the healing products was determined using various techniques (TGA, SEM/EDS and XRD). The primary results showed that using metakaolin and ground granulated blast furnace slag together greatly improve the healing efficiency.

Keywords: Autogenous self-healing, ground granulated blast furnace slag, metakaolin, mechanical properties, SEM/EDX, TGA, XRD.

Hydration of MgO/hydromagnesite Blends

Alexander German, Frank Winnefeld, Pietro Lura

Synopsis: MgO/hydromagnesite ($Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$, abbreviated as HY) blends are cementitious materials, which set and harden when mixed with water. These blends reach acceptable strengths and therefore can potentially be used as binders in mortars and concrete. In case MgO is derived from carbonation of magnesium silicates and subsequent calcination, MgO/HY blends offer the possibility to be used as alternative binders with reduced carbon footprint compared to normal portland cement-based products.
This study focuses on the characterization of hydration products and mechanical properties of MgO/HY blends. Hydration of solely MgO leads to formation of brucite ($Mg(OH)_2$) without any strength-building properties. In contrast, by blending MgO with hydromagnesite, it is possible to produce mortar samples with a strength of up to 11.0 ± 0.4 MPa (1595 ± 58 psi) after 28 d. Moreover, blending with hydromagnesite accelerates early hydration of MgO. XRD and TGA studies of hydrated blends revealed the presence of brucite and of a poorly crystalline, unidentified hydrate phase. The latter might play an important role in strength development.

Keywords: Alternative binder, artinite, brucite, cement, eco-friendly, hydromagnesite, magnesia

Early-Age Shrinkage of Cement Paste Containing Humic Substances as that from River Dredging Sediments in France

Hamza Beddaa, Amor Ben Fraj, Francis Lavergne and Jean Michel Torrenti

Synopsis: Dredged river sediments can be considered as a promising alternative for conventional aggregates in concrete. However, the effect of sediments' properties and particularly their organic matter (OM) content on those of the concrete have to be assessed. Indeed, the organic weight fraction of organic matter in sandy sediments dredged in the Seine watershed is highly variable as it varies from 0 wt% to 10 wt% of the dry matter. This research aims at assessing the effects of humic substances (HS) on the early age behavior of a cement paste. HS are organic compounds resulting from the chemical, physical and microbiological transformation of animals and plants residues and which are also the most representative component of sediments organic matter. A soluble HS, potassium humate, is added as partial substitution of cement; 0.2 wt%, 0.5 wt% and 1 wt%. The results indicate that HS causes a delay of both chemical and autogenous shrinkages by retarding the hydration process. In addition, the chemical shrinkage amplitude is not significantly affected by the presence of HS in the mixture, while the autogenous shrinkage is decreased especially for the high w/b (water/binder; binder=cement+HS) ratios, due to bleeding. Furthermore, for high rates (2% and 3%), this bleeding could generate a delay of setting between the top and the bottom of the sample causing cracks due to a restrained shrinkage in the upper part of the sample.

Keywords: autogenous shrinkage, chemical shrinkage, dredging sediments, humic substances

Effect of a Lignosulfonate Plasticizer on the Hydration of a Belite-Ye'elimite-Ferrite Cement Paste

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ABSTRACT

Belite-Ye'elimite-Ferrite (BYF) cements have been recently developed in order to substitute ordinary Portland cement (OPC), as they release up to 30 % less CO_2 and their performances tend to be similar. This work aims to give a first insight and understanding on the influence of a lignosulfonate plasticizer (LS) on the hydration and the properties of a BYF cement paste. For this purpose, hydration of neat cement paste (w/c=0.4) was followed by isothermal calorimetry associated with in situ XRD for the first 4 hours. In addition, plasticizer adsorption was investigated using TOC measurements. Rheological and compressive strength tests were also performed. The results showed that LS changes the hydration kinetics, modifying both induction period (that becomes shorter for low dosage and longer for higher dosage) and rate of ettringite precipitation. For all dosages used, LS decreases the heat of hydration and the compressive strength in the first day. Also, its impact on particle surfaces improves their dispersion and causes a diminution of the shear stress of cement paste, allowing better workability.

Keywords: Adsorption, belite ye'elimite ferrite (BYF) cement, lignosulfonate, yield stress

Shrinkage and Geopolymers

Corentin Le Talludec, Annabelle Phelipot-Mardelé, and Christophe Lanos

Synopsis: Geopolymers are interesting solutions to avoid the use of traditional portland cement. Many studies focus on geopolymers formulation and final performances highlighting the short setting time and the rapid increase of mechanical performances. However, it is necessary to adapt the formulation regarding the components (including origin, reactivity, chemical formula). The successive steps to achieve the geopolymerization of an aluminosilicate in alkaline media are very sensitive to any change in the molar ratios of Si, Al and M (cation) available in the solution. This study focuses on Na-geopolymers. Several formulations performed using metakaolin, silica fume and soda are tested. Samples are subject to mass monitoring and shrinkage measurement varying the curing conditions. Long stabilization times (one month), and significant shrinkage, in the order of 10 %, are quoted. The interaction between autogenous shrinkage and drying shrinkage is discussed. The link between volume and mass variations suggests a large contribution of the drying shrinkage. This phenomenon interferes with the last steps of geopolymerization leading to the hardening. The results show that a part of the formulation water remains trapped in the binder matrix after the geopolymerization. TGA analysis confirm the results. To limit the shrinkage, mix formulation is modified introducing various type of calcium silicate fillers.

Keywords: alkali activated binder, alternative material, drying shrinkage, geopolymer, shrinkage

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Acceleration of Cement Blended with Calcined Clays with CaCl2, Microlimestone and CSH seeds

Claudiane Ouellet-Plamondon, Sebastian Scherb, Mathias Köberl and Karl-Christian Thienel

Abstract: Supplementary cementitious materials (SCM) are needed to reduce the carbon impact of cementitious materials. Especially calcined clay mixtures are a sustainable alternative which is available abundant worldwide. Although strength of binders containing calcined clays may exceed at 28 days the reference cement, there is still one shortcoming: The early strength development is too slow for many applications. In order to overcome this obstacle calcium chloride, microlimestone and CSH seeds were tested in different dosages as hydration accelerator and the most promising dosage was determined by calorimetry and mortar tests. The accelerators increased the amplitude of the maximum heat flow and shortened the time when Qmax occurred compared to the blended binder made with calcined clay. They also acted as a strength accelerator. The reactivity index slightly increased with the calcium chloride and the microlimestone; with CSH seeds it was on the level of the blended binder.

Keywords: accelerators, calcined clay, calcium chloride, calorimetry, CSH seeds, in-situ X-ray diffraction, microlimestone, mortar, thermogravimetric analysis

Monitoring of Concrete Hardening and Strengthening Using Results of Electrical Resistivity Measurements (Theory and Practice)

David I. Stackelberg, Boris I. Wilge, Shimon V. Boiko and Felix A. Goldman

Abstract: Hardening and strengthening of cement-concrete compositions (CCC) is a result of forming a moist capillary porous body. Physical water contained in pores and capillaries of the resulting structure is its most informative component. First, it is only the pore solution that is electrically conductive component, and, second, the liquid phase stays perpetually in a thermodynamic equilibrium with the solid surfaces by which it is adsorbed. Thus the physical-moisture state immediately responds to any change in the material's solid skeleton of hardening CCC.

These effects serve as a physical basis for the CCC hardening and strengthening monitoring using the results of continuous measurement of electric resistivity. Such monitoring is aimed at controlling various properties of the material: from the initial viscous fluid or viscous plastic state of fresh mixtures to the final elastic state of artificial stone. The results of measuring the electric resistivity are compared to those of standard tests. Thus established relationships "Electric resistivity (ρ) – Parameters (P_i)" (Parameters: W/C, Slump, Setting Time, Plastic strength, Compressive Strength) allow to carry out technological monitoring over the entire range of CCC hardening. All correlations $P_i = f(\rho)$ are described by linear relations with high correlation coefficients.

The linearity of the correlations "Strength – Electric Resistivity" is characteristic of various CCC: regular dense concrete, dry concrete mixtures (W/C $\approx$ 0.35), shotcrete, rising and plastic strengthening of aerated concrete at the stage of pre-autoclave hardening, etc.

Keywords: compressive strength**,** concrete, electric resistivity, hardening, monitoring, pore solution, strengthening,

Performance of Eco-Friendly One-Part Alkali-Activated Self-Consolidated Concrete with Multi-Activators

Dima Kanaan and Ahmed Soliman

Synopsis: The feasibility of producing "just add water" alkali-activated self-consolidated (AASCC) mixtures using multi-powder activators and various cement-less binder combinations was evaluated in this study. During this study, fresh properties for mortar mixtures were evaluated by conducting the mini-slump flow test. Moreover, the relative performance of activated mortars and potential interactions among materials used in the mixtures was examined using the isothermal calorimeter. The performance of the hardened mortar mixtures was evaluated after 3, 7 and 28 days by conducting compressive strength tests. Results indicated an increase in the mechanical properties was observed while increasing the dry-powder activator ratio and source material nature for ground and non-ground mixtures.

Keywords: Alkali-Activated Materials, Sustainability, Eco-SCC, Alkali-Activated SCC (AASCC), One-Part, Dry-Powder

Studying the Influence of the Filler Effect of SCMs on the Sulfate Requirement of Blended Cements

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Abstract

It has been well stablished by several studies that LC^3 requires an additional amount of gypsum on top of the normal dosage contained in OPC. In this manner, the second (aluminate) peak do not overlap with the first (alite) peak. This required increase of the sulfate content is attributed to the additional aluminate phases introduced to the system by the addition of calcined clay. However, a correlation between metakaolin (alumininosilicate phase) content and the amount of additional gypsum required for proper sulfation has not been found, and the relationship between these parameters and the position of the aluminate peak is not clear. This study explored in depth this issue in order to further understand the driving mechanism controlling the sulfate demand in LC^3. Our results show that there is no direct link between the aluminate phase content and the gypsum demand. On the contrary, the driving mechanism is linked to the specific surface area that the mineral additions (calcined clay and limestone) introduce to the system, interaction commonly referred as filler effect.

Keywords: gypsum, ettringite, kinetics, hydration, aluminates, C-S-H, adsorption

On the Occurrence of CAH_{10} in Hydrated Calcium Sulfoaluminate Cements

Frank Winnefeld and Barbara Lothenbach

Synopsis: The occurrence of CAH_{10} in a calcium sulfoaluminate (CSA) clinker and in the CSA clinker blended with anhydrite was assessed by experimental data and thermodynamic modelling. For the CSA clinker it was found that CAH_{10} forms as an intermediate phase directly from the hydration of ye'elimite together with ettringite and aluminium hydroxide, which is an alternative reaction path to the formation of monosulfate and aluminium hydroxide. The occurrence of CAH_{10} is linked to the solubility of the aluminum hydroxide formed, which decreases with time due to an increase of its crystallinity. In case of a highly soluble aluminum hydroxide, which occurs at early hydration times, the formation of CAH_{10} and ettringite is thermodynamically more favoured than the formation of monosulfate. At later ages, when the solubility of aluminum hydroxide decreases, CAH_{10} and a part of the ettringite convert to monosulfate. This conversion is associated with an increase of porosity, which leads to a significant loss of compressive strength beyond a sample age of 28 days. In the CSA clinker blended with anhydrite the formation of CAH_{10} could not be evidenced. No loss of compressive strength was observed for this sample.

Keywords: Aluminum hydroxide, CAH_{10}, Calcium sulfoaluminate cement, hydration, thermodynamic modelling

An Innovative Power-Law Equation of Optimal Grading Curves for Dense Packing

Dr Gerard Roquier

Synopsis: The search for the optimal grading curve remains an open problem for dense packing in the field of concrete. In France, Caquot considered that the coarsest fraction is the only one that is not submitted to the wall effect. In a grading span and in the case of a fifth root of the diameter as the abscissa parameter, he found a fairly straight broken-line. In some other countries, the Andreasen and Andersen (A&A) cumulative distribution function is a power-law equation with a distribution modulus commonly equal to 0.4 or 0.5. How to unify these two approaches? Validated for ordered and disordered packings and for different particle shapes and textures, the recent Theoretical Packing Density Model (TPDM) clarifies the situation. Firstly, the TPDM highlights curves evolving from A&A's to Caquot's as the packing process, characterized by a compaction index K, becomes more and more efficient. Secondly, an innovative power-law equation is proposed to unify the two approaches of A&A and Caquot. The distribution modulus is composed of: K, a constant q, the compaction index corresponding to a pouring process K_{min} and the ratio d/d_{max} where d is the particle diameter and d_{max} the largest particle size in the distribution.

$$P(d) = \left(\frac{d}{d_{max}}\right)^{\left(q + \left(1 - \frac{K_{min}}{K}\right)\left(\frac{d}{d_{max}}\right)\right)}$$

Keywords: continuous distribution, optimal grading curve, packing density, particle size distribution, Theoretical Packing Density Model (TPDM).

ASSESSMENT OF PROPERTIES OF LOW CEMENT CONTENT PASTE USING INTERPARTICLE SEPARATION AS AN INSIGHT ON FRESH STATE

Gonzalo A. Lozano Rengifo, Mayra T. de Grazia, Leandro F. M. Sanchez, Edward G. Sherwood

Abstract: Reducing Normal Portland Cement (NPC) has been a major concern of concrete industry and research community over the last 2-3 decades. As much as 8% of the global CO_2 emissions stem from clinker production. Hence, a wide number of research projects have been focusing on reducing NPC in cementitious materials using numerous strategies such as the use of supplementary cementing materials (SMC's), limestone fillers (LF) and/or advanced mix-proportioning techniques. Yet, the impact of these procedures on the overall behaviour of materials with low NPC content, especially in the fresh state and long-term durability, is still not fully understood. This work aims to understand the influence of the distance between the fine particles, the so-called Inter-Particle Separation (IPS), on the fresh state behaviour of cement-base pastes designed through the use of Particle Packing Models and incorporating LF. Evaluations on the fresh (i.e. rheological behaviour and setting time) and hardened states (compressive strength) were conducted in all mixtures. Results show that IPS directly correlates with the viscosity of cement-base pastes for all shear rates appraised. Moreover, the use of LF increases the hydration rate of NPC pastes. Finally, it is clear that the water-to-cement ratio keeps being the main factor controlling the compressive strength of cement pastes with reduced NPC content and high levels of LF replacement.

Keywords: Inter-Particle Separation distance **(**IPS), limestone fillers, (LF) Particle Packing Models (PPM), setting time, rheology, viscosity.

Portland Clinker-Fly Ash Cements – Relation between Compressive Strength and Microstructure

Harald Justnes, Klaartje De Weerdt and Tone A. Østnor

Synopsis: Portland cements were made by mixing 4 different clinkers with 2 gypsum levels and 0-5% limestone powder. The compressive strength after 28 days of curing varied from 40 (5802) to 70 MPa (9718 psi) for mortar with equal w/c. Some of the clinkers were replaced with 4 different fly ashes and the response on strength differed. To explain the relatively large differences in strength evolution, the clinker and fly ash composition was investigated by SEM-BSE/EDS, the oxide compositions were determined by XRF and differences in clinker mineralogy determined by XRD Rietveld analysis. The microstructure of hydrated cement pastes of clinker/fly ash was investigated by SEM/EDS.

The highest strength was achieved with the white clinker containing no C_4AF, produced using $CaSO_4/CaF_2$ flux, and therefore contained a higher total calcium sulphate content. The white cement also seemed to contain two calcium aluminate phases with potentially some fluoride in one of them, one probably glassy as Rietveld analysis underestimated C_3A. The C_4AF content of the other clinkers have low reactivity within the 28 days explaining some of the difference. One "fly ash" was actually a fluidized bed ash with higher calcium and sulphate content and different morphology explaining the different behavior from the other fly ashes.

Keywords: clinker, compressive strength, fly ash, microstructure, sulphate

Effect of Recycled Aggregate and Steel Fibers on the Mechanical Properties of Alkali-Activated Slag/Fly Ash Blended Concrete

Jamal Medljy, Hilal El-Hassan, Tamer El-Maaddawy

Synopsis: This paper focuses on developing ambient-cured alkali-activated concrete incorporating recycled concrete aggregates (RA). The binder was either slag or a blend of slag and fly ash (3:1, by mass). Hook-ended steel fibers were added, in 2% volumetric fraction, to improve the properties of concrete made with RA. The alkaline activator solution was a blend of sodium silicate and sodium hydroxide. Concrete mixtures were proportioned to achieve three target compressive strengths, namely 30, 45, and 60 MPa. The performance of concrete mixtures was assessed based on 1, 7, and 28-day compressive strengths. Experimental results showed that full replacement of natural aggregates by RA caused up to 28% reduction in compressive strength of plain alkali-activated slag concretes, with greater reductions being reported in mixtures with higher target strength and tested at 28 days. The incorporation of 2% steel fibers enhanced the strength and caused limited strength reductions of up to 7%. Compared to alkali-activated slag RA concretes, mixtures with 25% fly ash replacement exhibited lower strengths at 1 and 7 days, but their 28-day strength was superior. Analytical multi-linear regression models were developed to identify statistical significance of concrete components and examine their impact on the compressive strength.

Keywords: alkali-activated concrete, compressive strength, recycled aggregates, regression models, steel fibers

New Pre-saturation Method for Accelerated Sulfate Attack Testing of Concrete Specimens

Hocine Siad, Mohamed Lachemi, Mustafa Sahmaran

Synopsis: This paper studies the use of a new preconditioning process for an accelerated testing of concrete resistance against sulfate attack. For this reason, concrete specimens were subjected to a part by part pre-saturation method using a concentrated sulfate solution drained inside desiccators. This preconditioning technique was applied before exposing the specimens to different immersion conditions in 5% and 10% sulfate solutions, and to storing at high temperature and to wetting/drying cycles. Length change measurements and sulfate penetration profiles were performed on normal and high strength concretes. In addition, SEM-EDS analysis were used to investigate the type and amount of degradation products in the core layer of samples exposed to accelerated testing. The new pre-saturation method highly accelerated the degradation of concrete samples exposed to different immersion conditions. The microstructural observations showed advanced depths and greater amounts of gypsum and ettringite within the degraded specimens subjected to the primary preconditioning stage. However, the real field observations were only achieved when combining the pre-saturation method and the immersion in 5% sulfate solution.

Keywords: Concrete; Expansion; Microstructure; Pre-saturation; Sulfate attack; Sulfate profiles

The Influence of the Binder and Aggregate Type on Concrete Electrical Resistivity

Hugo Valido Deda, Leandro Francisco Moretti Sanchez, Mayra Tagliaferri de Grazia

Abstract: Although the 28-day concrete compressive strength is often used as a quality control indicator, early-age mechanical properties are becoming more critical to optimize construction scheduling. Numerous advanced techniques have been proposed in this regard and among those, electrical resistivity (ER), a non-destructive and inexpensive technique able to characterize the microstructure development of cementitious materials has been showing promising results. Yet, recent literature data have evidenced that ER might be significantly influenced by a variety of parameters, such as the binder type/amount and aggregates nature used in the mix. These factors can hinder the practical benchmark of concrete mixtures proportioned with distinct raw materials. Thus, six concrete mixtures incorporating two types of aggregates (granite and limestone) and two ground granulated blast furnace slag cement replacements (e.g. 0%, 35%, and 70%) were manufactured for this research. Moreover, three distinct ER techniques (e.g. Bulk, Surface, and Internal) and compressive strength tests were performed at different concrete ages. Results show that the binder replacement may significantly affect ER results over time, whereas the aggregate type presented a less significant impact.

Keywords: Concrete microstructure, electrical resistivity, non-destructive testing, supplementary cementitious materials.

Carbonation of 100-year bridges as a guide to preventing modern concrete from degrading

Ivan Janotka[1,*], Michal Bačuvčík[1] Peter Paulík[2], Lukáš Húlek[1]

Synopsis: A layer of 2-4 mm (0.08-0.16 in) protective render coat (PRC) has proven to be an effective anti-carbonation barrier at two bridges protecting the underlying concrete against carbonation for 100 years. The carbonation of concrete under the PRC with low permeability was found to be less than 2 mm (0.08 in). It is assumed that the PRC was placed for aesthetic purposes. Taking into account the considered XC3 exposure class according to EN 206, to which concrete structures were subjected and compressive strengths of the underlying concrete between 20 - 25 MPa (2900 - 3625 psi), low carbonation depth can be explained by the presence of the PRC applied on concrete surface. The main scientific goal of this article is to explain the cause of extremely low carbonation depth of concrete under the PRC. Its composition has been unknown until now but the present research reveals the secret of this substance. Investigations of the aspects of low carbonation depth thoroughly focused on the PRC role covering concrete beneath as well as material development of new current PRC based on the present cement and sand, without the use of chemical admixtures, are also the subject of ongoing research.

Keywords: carbonation, concrete, 100-year bridge, protective render coat, resistance

Rheology and Mechanical Properties of Different Geopolymer Composites

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Synopsis: This work aims to study the influence of the shaping process on the mechanical properties of geopolymer composites reinforced with glass fibers and wollastonite. To this end, the synthesis feasibility of two geopolymer composite formulations was first determined. The influence of casting, extrusion and robocasting on mechanical properties was then studied with compressive and three-points bending tests and microstructural analysis. The results showed that the casting process is preferable to be used for low viscosity geopolymer composite while robocasting is more appropriate for geopolymer composite with high viscosity. The extruded and cast samples exhibit similar compressive data's. The microstructural analysis showed that the robocasting process orients the fibers in the printing direction with an undefined interlayer. The casting process leads to a homogeneous material while the robocasting process conducts to an anisotropic material.

Keywords: casting, composite**,** geopolymer**,** mechanical**,** process, robocasting**,** shaping

EFFECT OF AGGREGATE TYPES ON MORTAR PROPERTIES PRODUCED WITH GEOPOLYMER BINDERS

Klaus-Juergen Huenger, David Kurth, Maria Brigzinsky

Synopsis: Alumino-silicate compounds (geopolymers) are important for alternative binders for mortars and concretes. Such systems normally have a solid (metakaolin, slag, ash) and a liquid (activator solution) component. A newly developed system here consists of a waste silicate material and an aluminate source, both with a very good solubility. Under the addition of water only, a structure formation process occurs to form an alumino-silicate network. The Si/Al ratio can be varied in wide ranges to produce binders with different properties.

It was very surprising that the mortar properties not only depend on the recipe, but also on the aggregate types. Different aggregate types (quartz, greywacke, rhyolite, diabas, basalt, granodiorite) were chosen to produce mortar bars. All components were intensively mixed dry or as a slurry. Already the sand component affects the workability, further the setting time, the strength development and, of course, the durability. The best results were obtained with quartz, the worst with diabase or basalt sands. Obviously, the chemical and mineralogical composition and therefore the soluble constituents of the sand under highly alkaline conditions affected the structure formation process of the alumino-silicate binder and therefore the mortar properties too. The observed effects have nothing to do with an Alkali-silica-reaction (ASR).

Keywords: alumino-silicate structures, industrial residues, mortar properties, sand types, Si/Al ratio,

Industrial Mineral Waste as an Alternative Pozzolan for the Design of Eco-Efficient Binary Cements: Impact on Physical Properties and Chloride Resistance

Laura Caneda-Martínez, Moisés Frías, Mª Isabel Sánchez de Rojas, Javier Sánchez, and César Medina

Synopsis: The current exponential growth in cement demand and the gradual reduction in the availability of the supplementary cementitious materials (SCMs) conventionally employed in the cement sector (fly ash, blast furnace slag, etc.) have brought awareness over the need to find alternative sources of pozzolanic materials. Whereas the use of calcined kaolinitic clays (metakaolinite) could represent an excellent substitute for the traditional SCMs, the environmental and economic cost associated with kaolinite extraction thwarts the development of this course of action. Conversely, the clayey wastes obtained in the coal mining industry could represent an inexpensive and environmentally sound raw material for the production of recycled metakaolinite, promoting at the same time a Circular Economy model.

This work describes the physical and durable properties of binary mortars prepared with different substitution levels (20 % and 50 %) of thermally activated coal mining waste (600 ºC/2 hours), placing emphasis on their chloride resistance. The results show that the differences observed in the pore network and in the mineralogical composition of the blended matrices result in a superior resistance to chloride ingress and, therefore, in a decrease in the risk of corrosion of the subsequent structures and an increase in their service life.

Keywords: coal mining waste, supplementary cementitious materials, eco-efficient cements, chloride resistance, porosity, resistivity, chloride diffusion coefficient, critical chloride content

An insight into non-ferrous slags as supplementary cementitious materials

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Synopsis: In this work, a non-ferrous metallurgical slag has been characterized and its reactivity has been assessed and compared to current SCMs. Additionally, the hydration of a blend of portland cement with 30 wt. % replacement by slag was investigated for hydration kinetics, hydrate phase assemblage and mechanical strength up to 91 days using isothermal calorimetry, XRD and compression tests. The reactivity tests revealed pozzolanic reactivity of the slag and a dissolution behavior comparable to fly ash. The hydrate phase assemblage of the PC-slag blend showed a difference in the AFm phases forming compared to the portland cement reference, which was suggested to be due to the incorporation of Fe. The compressive strength after 28 days of hydration was correlated with the cumulative heat after 7 days of hydration and then compared to current SCMs. Also these results show that the non-ferrous metallurgical slag compares to siliceous fly ash. Hence, this work shows that Fe-rich non-ferrous slags are suitable candidates as SCMs in portland cement.

Keywords: hydration, non-ferrous slag, reactivity, supplementary cementitious materials

Boron Rich Mortars for Neutron Shielding, Mechanical and Attenuation Properties

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Synopsis: Boron thanks to his high neutron cross section is an effective absorber of thermal neutrons. Mortar manufacturing with a useful boron contents is particularly relevant for neutron shielding applications. The use of natural boron rich minerals or synthetic boron compounds as sands is an affordable route for boron charged mortars. Nowadays, a largely available boron rich mineral is colemanite, which is a calcium borate hydrate with an atomic boron content of 15.78 wt%. Nonetheless, colemanite in contact with cement pore solution is partially soluble and releases boron species harmful to C3S hydration.

We investigated the effect of inserting colemanite in normal portland cement mortars by varying the grain size of colemanite sand and evaluating the mechanical and neutron attenuation properties of mortar samples. Additionally, we tested danburite that is a boron rich silicate mineral as an insoluble mineral alternative. Danburite is certainly less available than colemanite, but it can be produced via hydrothermal synthesis starting from colemanite and a reactive silica source.

The results shown that a 3.2% of atomic boron on total weight of mortar can be achieved without compromising the mechanical properties with selected colemanite grain size.

Keywords: boron mortars; boron silicates; colemanite; danburite; neutron shielding.

Preliminary studies on the influence of nano-cellulose and nano-alumina fibers on UHPFRC

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Synopsis: Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC) is a type of concrete with superior mechanical and durability properties, which might be improved even further with the addition of nano-materials. This work studies the influence of adding nano-additions to two UHPFRCs with compressive strength around 150MPa (*21755 psi*), with and without crystalline admixtures. Two nano-materials were considered: cellulose nano-crystals (4-5 nm diameter, 50–500 nm length, *0.157-0.197 µin diameter, 1.97-19.7 µin length*); in a dosage up to 0.15% by the cement weight; and aluminum oxide nanofibers (diameter 4-11nm, length 100-900nm, *0.157-0.433 µin diameter, 3.94-35.4 µin length*) in a dosage of 0.25% by the cement weight. Water content of the mixes with nanomaterials was modified to maintain workability in a similar range aiming to maintain the self-compacting behavior. The following properties were analyzed: workability, compressive strength, modulus of elasticity and tensile properties calculated through a simplified inverse analysis after performing four-point bending tests. The study considered the effect of using three levels of mixing energy to ensure a proper dispersion of all the components, and its effect in the aforementioned properties. The results show a potential effect of these nanomaterials as nano-reinforcement, with slightly better ultimate strength and strain values for the higher energy level.

Keywords: aluminum oxide nanofibers, energy, nanocellulose, nanomaterials, UHPFRC

INTERACTIONS BETWEEN SCM`S AND DIFFERENT AGGREGATES FOR PREVENTING ASR

Klaus-Juergen Huenger and Mario Kositz

Synopsis: Supplementary cementing materials (SCM) have a great importance for preventing ASR in concrete structures worldwide. Different materials were used, e.g. fly ashes, silica fume or metakaolin. However, the results are often contradictory. What works with one aggregate does not necessarily work with another, or in other cases, the efficiency is not the same. Not all effects can be explained by fluctuations in the SCM composition.

Long-term investigations were carried out using three different aggregates. Concrete prisms were produced, and parallel aggregates were stored together with different SCM`s (different types and concentrations) in highly alkaline solutions with and without calcium hydroxide in the system. The reaction products, which precipitated as a result of the interactions between aggregate and SCM`s at different storage times, could be investigated by NMR and even XRD. The results were surprising because different aggregates formed different reaction products when using the same SCM. Such effects can only be explained by the release of different soluble minerals that are part of aggregates.

The conclusion is that obviously aggregates control the formation process of reaction products which are formed as a result of the interactions between SCM`s and aggregates. And these products are responsible for preventing ASR when using the SCM`s.

Keywords: Supplementary Cementing Materials, ASR inhibition, solubility experiments, aggregate types, reaction products

On the Formulation of Reactive Binders Containing Soluble Borate Compounds

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Synopsis: Boron efficiently absorbs neutrons due to its large cross section. Thus, boron containing materials are an effective shield to neutrons and are commonly used as containment barriers in nuclear reactors. The most economical way to include boron into shielding structures is to prepare B-rich mortars or concretes, to be used as structural elements or as plastering. However, colemanite [$Ca(B_3O_4(OH)_3)\cdot(H_2O)$], the most abundant B-containing mineral, is sufficiently soluble to release enough borate ions in solution to indefinitely stop Portland cement hydration.

Here we present the formulation of hydraulically active binders containing 50% of colemanite. They are based on blends of calcium aluminate cements and blastfurnace slag. The main hydration product in the absence of colemanite is strätlingite along with other AFm phases. MgO causes an increasing hydrotalcite precipitation, and fly ashes further increase strätlingite content. The presence of colemanite causes the precipitation of B-ettringite, where $B(OH)_4^-$ ions substitute for sulphate ions. These binders set in one day and harden in 4 days. The addition of hydrated lime in the formulations brings about the additional precipitation of B-containing AFm phases, where the trigonal HBO_3^{2-} ion constitutes the interlayer between positive $[Ca_2Al(OH)_6]^+$ sheets. These binders set in few hours and harden in one day.

Keywords: boron minerals, colemanite, cement setting, hydration retardation, neutron shielding.

Unintended consequences of the global reduction in clinker-to-cement ratio

Jean-Martin Lessard, Guillaume Habert, Arezki Tagnit-Hamou and Ben Amor

Synopsis: To decarbonize the portland cement sector worldwide, the *Cement Sustainability Initiative* recommends systematically reducing the clinker-to-cement ratio down to 60% by 2050. However, the sources of usable clinker substitutes - the supplementary cementitious materials (SCMs) - are unevenly distributed geographically and will become increasingly scarce in the future. Through a time-series material-product chain analysis, this paper investigates the multi-regional and multi-sectorial (cement, coal-fired electricity, and steel sectors) interactions that occur when increasing demand for SCMs in eastern Canada and Northeastern U.S., up to 2050. It tracks the trade effects and how it affects region-specific domestic flows of raw and secondary materials, end-product products, and greenhouse gas emissions. Although the lever is favorable overall, the results show unintended economic and environmental consequences across regions, with winners and losers. At the *material level*, benefits are influenced by the local availability of SCMs, which disadvantages Canadian regions due to the increasing remoteness of supply to meet demand. At the *product level*, decoupling blended cement production capacity from clinker production capacity allows the U.S. regions to reduce their dependence on Canadian cement imports. These new perspectives provide key geopolitical, environmental, and economic insights for better decision-making when developing sustainable initiatives.

Keywords: Economic optimization, Environmental impact, Material flow, Multiregional industrial symbiosis, Supplementary cementitious materials, Supply chains, Trade effects

Effect of citric acid and polycarboxylate superplasticizers (PCE) on hydration and rheology of sulfoaluminate cement

R. BELHADI, A. GOVIN, and P. GROSSEAU

Synopsis: The production of normal portland cement (NPC) accounts for about 5%-7% of the total man-made CO_2 emissions. One of the low CO_2 alternatives to NPC is sulfoaluminate cement (CSA), mainly composed of ye'elimite (C_4A_3S), belite (C_2S) and sulfate source (CS or CSH_2). Its main hydrated phase is ettringite ($C_6A_3SH_{32}$). CSA are known for their poor workability and their short setting time, which require the use of superplasticizers and retarders.

The aim of this work is to investigate: (i) the effect of citric acid and polycarboxylate superplasticizers (PCE) on the hydration and rheology of CSA; and (ii) the effect of citric acid on the dispersing effectiveness of PCEs. Two PCEs, with the same chemical structure and different molecular structure, were studied. Isothermal calorimetry and thermogravimetric analysis (TGA) were used to describe the hydration process, while rheological properties were characterized with a flow test. Adsorption measurements were carried out with total organic carbon analyzer and ionic chromatography. The results show that the combination of citric acid and PCE allows better retention of workability over time. However, a competitive adsorption between citric acid and PCE decreases the initial dispersion.

Keywords: Citric acid, competitive adsorption, CSA, dispersing effectiveness, hydration, polycarboxylate superplasticizer (PCE)

Influence of calcite on the pozzolanic reaction of kaolinite

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Synopsis: The use of kaolinite as a pozzolanic activator in the hydration of cement is widely established. The optimum calcination conditions and the scientific basis of the reaction kinetics for the systems metakaolinite (MK)/lime, used as a standard system, and metakaolinite (MK)/cement have been set. These treatments reach their maximum effectiveness in the presence of non-altered calcite. The objective of this research is to determine the influence that calcite has on the pozzolanicity of the kaolinite, in order to do so, different mixtures kaolinite (K)/calcite (Ca) thermally activated at 600ºC and 750ºC for 2 hours were prepared. The products obtained in the pozzolanic reaction were studied with XRD and SEM/EDX analysis. The calcite addition generated an inhibitor effect in the reactivity of natural kaolinite (K) when the thermic activation is at 750°C for 2 hours. The optimal calcination conditions regardless of the proportion of calcite are 600°C/2 hours.

Key word: activation thermically, calcite, cement, hydrated phases, kaolinite, pozzolanic reaction, kaolinite

Mechanical and Physical Properties of Concrete Incorporating Rubber

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Synopsis: Scrap tyres are one of the most serious wastes that are landfilled with small percentages. Recycled scrap tyres are being used in different domains of industry because they are not-degradable. The experimental work focused on mechanical properties and durability indicators of self-compacting sand concretes blended with recycled rubber. Such modified concretes comprised 5, 10, 15 and 20% of rubber fine powder (RFP) and coarse particles (RCP) as partial substitutions of natural sand and aggregates. To shed light on physical and mechanical properties rubber particles effects, ordinary vibrated and self-compacting as well as self-compacting sand concretes (SCSCs) were characterised. Special attention was given to compression and bending performances of SCSCs. Identification of two durability indicators — water porosity and density — was assessed, according to AFGC specifications. Experimental findings enhanced previous literature reported statements and demonstrated that use of rubber particles as substitutes improved performances of elaborated SCSCs and produced eco-friendly materials that are appropriate for large surface applications such as pavements and terraces as well as civil engineering constructions.

Keywords:
Self-compacting sand concrete; Vibrated concrete; Recycled rubber; Compressive strength; Flexural strength; Water porosity.

Early hydration process of a low shrinkage and high strength packing density optimised mortar-mixture made of an alternative NPC-CSA-CA blend

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Synopsis

Compared to normal concrete, packing density optimised Ultra High Performance Concretes have a high shrinkage up to 1 mm/m due to their high cement content. Especially in the first 24 hours approximately 80 % of the final shrinkage is reached which reduces the early strength due to microcracks. Instead of additives within the scope of this research work, parts of normal portland cement (NPC) were substituted by Calcium Sulfoaluminate (CSA) Cement and Calcium Aluminate (CA) Cement with the aim to reduce shrinkage of UHPC-mixture as well as a fast setting. CSA-cements with low CO_2 footprint are characterised by their fast strength development and expansion behaviour due to early ettringite formation. X-ray diffraction was used to study the phase development. The influence on the shrinkage value was measured by shrinkage tests. In addition, the development of the microstructure was investigated by scanning electron microscopy. Finally, the influence on the strength development was correlated by ultrasonic measurement. These techniques allow a prediction of the setting process in the early stages. Finally, an environmentally friendly NPC-CSA blend could be developed which, in addition to high early strength, also achieves low shrinkage. Furthermore, the influence of the ettringite formation on the microstructure could be determined.

Keywords: Calcium Aluminate Cement, Calcium Sulfoaluminate Cement, ettringite formation, packing density optimised concrete, setting behaviour, shrinkage

Synergetic Effect of Combined Converter Steel Slag and Metakaolin Hydration

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Abstract - Converter steel slag exhibits very low hydration activity compared to ordinary portland cement. To increase its reactivity, a mixture with metakaolin ($Al_2O_3 \cdot 2SiO_2$) was designed to increase the binding capacity. Metakaolin was used for its purity and high pozzolanic reactivity, owing to its high alumina and silica content. Two systems were prepared, metakaolin and portlandite as a reference, and the second system was composed of converter slag and metakaolin. Reactivity was assessed by measuring the heat release of the hydration reactions by isothermal calorimetry. Calorimetry results show the cumulative heat of converter slag increases when metakaolin is added. Furthermore, new hydration products were identified. Large area phase mapping based on SEM/EDX spectral imaging was done to investigate the reactions between the components.

Keywords: converter steel slag; metakaolin, mineralogy, reactivity.

POTENTIAL CORRELATION BETWEEN YIELD STRESS AND BLEEDING

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ABSTRACT

Since both the yield stress and bleeding originate from the network of interacting cement particles, their correlation seems to be possible. The purpose of this paper is to investigate the existence of this correlation by varying solid volume fraction of cement paste. The static yield stress measurements were carried out using a traditional rheological test, and bleeding was determined by turbidimetry measurements. It appears that the correlation between yield stress and bleeding depends strongly on the solid volume fraction.

Keywords: bleeding, interparticle force, particle size, volume percolation, yield stress

INTRODUCTION

The better understanding of the fresh state of cement based materials allows formulating special concretes such as self-compacting concrete[1]. Such concrete is able to flow under its own-weight and can stay homogeneous by reducing instability phenomenon such as segregation and excessive bleeding. The first property is related to the stress required to initiate flow, i.e the yield stress, while the second involves the resistance of particles to bleeding and segregation, which is related to yield stress and viscosity.

Macroscopic Evaluation of Water Penetration Resistance in Concrete with Neutron Imaging

Yuichi Yoshimura, Maki Mizuta, Hideyuki Sunaga, and Yoshie Otake

Synopsis: The development of a method to evaluate water penetration in concrete is beneficial for analyzing the durability of concrete structures since water in concrete affects the progress of degradations such as salt attack, carbonation, alkali silica reaction. However, water in concrete is generally detected by an embedded electric moisture sensor, it is difficult to obtain continuous spatial distribution about water diffusion. Water penetrated into concrete with a thickness of 5 cm was observed by neutron imaging using a room-size neutron source based on a compact accelerator and macroscopic analysis on water penetration was carried out. The results showed that the neutron transmittance corresponds to the water content and the moisture profile. Then transfer properties of water in concrete were obtained nondestructively and quantitatively. In addition, the relationship between the test results evaluating void structure and the water penetration resistance was considered. This report shows a new simple method to evaluate water penetration in concrete.

Keywords: neutron, compact neutron source, neutron transmission imaging, water content, water penetration, water penetration rate coefficient

Durability of alkali-activated slag/fly ash pastes and concretes: an overview of performance regarding freezing and thawing, surface scaling, shrinkage and ASR

Alexandre Rodrigue, Josée Duchesne, Benoit Fournier and Benoit Bissonnette

Synopsis: Alkali-activated slag/fly ash concretes activated with combined sodium silicate and sodium hydroxide show good mechanical and durability properties in general. When tested in terms of resistance to freezing and thawing cycling in water-saturated conditions, the concretes tested in this study show final values of relative dynamic modulus averaging 100% after 300 cycles. However, all tested concretes showed poor performance towards freezing and thawing in presence of de-icing salts with only one tested mixture showing a final average scaling value below 0.5 kg/m². Early-age microcracking is observed on all tested concretes and is correlated to high values of autogenous shrinkage in equivalent paste mixtures. Increasing the fly ash content reduces both the observed autogenous shrinkage and early-age cracking. Low drying shrinkage values ranging from 470 to 530 µm/m after 448 days of measurements at 50% RH and 23°C are noted. The use of fly ash in these alkali-activated concretes reduces the expansion levels of concrete specimens incorporating alkali-silica reactive aggregates. With increasing fly ash contents (20, 30 and 40% replacement), decreasing expansions are observed for any given reactive aggregate. In general, the durability properties measured in this study were improved by partially substituting slag with fly ash as binder material.

Keywords: Alkali-activated concrete, ASR, de-icing salts, durability, freezing and thawing, scaling, shrinkage

Impact of OPC-based Activation on Microstructure of Super Sulphated Slag Cement

By Emmanuel Guillon and Catherine Bouillon

Synopsis: The industrialization of Super Sulphated Slag Cement requires a strict control of the activation of slag. Optimal activator content is a compromise between early age and long term strengths. In particular, an excessive activator dosage leads to a strong decrease of final strength that could lead to non-conformities. Thanks to the coupled use of mechanical testing, SEM and isothermal calorimetry, this paper provides a clearer insight on how SSSC reacts. It is shown that excess of activation impacts mechanical strength twofold. First, it is observed after one or two days of hydration a decrease of hydration kinetics that could be attributed to a denser or thicker hydrate layer around slag particles. Second, overactivated SSSC exhibit heterogeneous porosity including defects that leads to a decrease of strength and lower mechanical efficiency. Finally, this paper highlights that the increase of strength observed when using hemihydrate is mainly due to the improvement of hydration kinetics, more than a gypsum setting effect.

Keywords: activation, calorimetry, hydration, low carbon concrete, microstructure development, super sulphated slag cement

Effect of Morphological Characteristics on the Viscosity of Cementitious Materials: Optimization of the Rheological Behavior of Ternary Cements

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Synopsis: Low environmental impact binders, in which clinker is partially substituted by less reactive powders, are used in proportioning low water-to-cement ratios mixtures to ensure higher compactness, low porosity and improved mechanical as well as durability properties. The use of relatively high solid volume fractions dramatically affects the workability of the mixture and affects its ease of placement and consolidation. Various superplasticizer types have been investigated in literature to control the rheological properties, although these admixtures considerably decrease the yield stress values, their effect on viscosity is moderate. The main objective of this investigation is to control the rheology of ternary cements by controlling the morphology of particles, which is the key parameter affecting the rheology of cementitious suspension. The test results on LC3 (i.e. 55% Portland cement + 30% calcine clay + 15% Limestone) and CEM II/B-M (S-LL) (i.e. 65% Portland cement + 20% Slag + 15% Limestone) ternary binders revealed that the optimization of the particle-size distribution and the maximum packing fraction of the powders leads to a considerable decrease of both viscosity and yield stress by 20% and 50%, respectively.

Keywords: morphological properties, optimisation, rheology, ternary blended cements

Effect of temperature on the hydration of portland cement blended with metakaolin

Natechanok Chitvoranund, Barbara Lothenbach, Jørgen Skibsted, Karen Scrivener

Synopsis: The effect of temperature on the hydration of portland cement blended with 20% of metakaolin is studied in a temperature range of 5 to 40°C. Temperature affects microstructure, phase assemblage, and transport properties. Temperature shows a strong influence on the microstructure at early age in both systems because it enhances the reactivity. At late age of hydration, the inner product formation of the blended system is less developed at higher temperature. The hydrated phase of the blended with metakaolin is more sensitive to the temperature than the plain system. In particular, the AFm and AFt phases vary depending on the temperature. The microstructure governs the transport properties of cements; the blended system shows a lower bulk conductivity. The reactivity of metakaolin is slow at lower temperatures resulting in a high bulk conductivity at early age in the blended system.

Keywords: blended cement, hydration, metakaolin, microstructure, temperature

Durability issues of one-part alkali-activated mortars in aggressive environments

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Synopsis: This paper presents an experimental study carried out to investigate the durability of one-part alkali-activated slag (AAS) mortars in different aggressive environments, such as chloride- and sulphate-rich solutions or in presence of freezing-thawing cycles. The mixtures were manufactured at equal water content and were activated by using sodium silicate, potassium hydroxide and sodium carbonate in powder form. In particular, the behavior of AAS mortars with different alkali content was compared with that of mixtures based on Portland cement and blast-furnace cement. Results show that the alkali content is a key-parameter for the durability of these innovative binders. In fact, in mortars manufactured with an alkali content higher than 0.06 by binder mass, the strength loss is similar to those of mixtures based on blast furnace cement after 150 freeze/thaw cycles. On the contrary, the sulphate-rich solution promotes a stronger degradation of the slag-based mortars respect to that shown by cement-based mixtures, regardless of the alkali content. Finally, the strong deterioration of cement matrix promoted by the formation of oxychloride in $CaCl_2$-rich environment is negligible in AAS mortars due to the lack of calcium hydroxide in the slag matrix.

Keywords: Alkali activated materials; Ground granulated blast furnace slag; Sustainability; Durability.

Characterization of calcined clay reactivity for use as additive in a blended cement

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Synopsis : Although normal portland cement is made from natural and recyclable materials its manufacture causes significant pollution, especially because of clinkerization which leads to important CO_2 releases into the atmosphere. The use of supplementary cementitious materials (SCMs) to partially replace clinker in normal portland cement and reduce its environmental cost is now well known (e.g., fly ash, metakaolin, glass powder or blast-furnace slag). This study investigates the potential for calcination and reactivity of a carbonate sample containing phyllosilicates. Samples were calcined at different temperatures and investigated using X-ray diffraction (XRD) with Solid State Nuclear Magnetic Resonance (NMR). The results show that the calcination of the sample leads to a dehydroxlation phenomenon of the clay fraction resulting in a change in the coordination of the aluminium atoms. Furthermore, the reaction between the Dolomite and the Palygorskite present in the sample leads to the formation of poorly-crysallized Belite during calcination. Hydration tests on the red-clay sample have demonstrated the hydraulic reactivity of the Belite and the pozzolanic reactivity of the calcined Palygorskite that lead to the formation of hydrates phases (C-S-H ; C-(A)-S-H). The multi-technique analysis applied in this study allows to highlight a direct correlation between the structural modification induced by calcination and the reactivity of the calcined sample.

Keywords: belite, blended cement, calcination, clay, dehydroxylation, palygorskite, pozzolanic activity

Use of Slag in Cementitious Matrices for Sprayed Concrete Applications

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Synopsis: The use of additions to replace cement in sprayed concrete applications is crucial in order to obtain matrices with proper mechanical properties and durability. Blast-furnace slag is not commonly employed to produce sprayed concrete because of its low reactivity. In this context, the objective of this study is to evaluate the chemical and mechanical properties of sprayed concrete produced with cement and blast-furnace slag as a partial cement replacement. Hydration kinetics were characterized by isothermal calorimetry, while mechanical properties were evaluated by needle penetration resistance and compressive strength of extracted cores. Results showed that slag was activated by accelerators and the resulting matrix fulfilled the requirements of the strength class J_2. Therefore, blast-furnace slag may be used in sprayed concrete when the average strength class is specified.

Keywords: Accelerator, blast-furnace slag, hydration, mechanical properties, sprayed concrete.

Study of Slag Blended Cement and the Influence of Triethanolamine

Rachel Reiver, Nathalie Azéma, Gwenn Le Saoût, Lucia Ferrari, Marie Jachiet, Vanessa Kocaba

Synopsis: Ordinary Portland cement (OPC) production contributes significantly to greenhouse gas emissions. Substituting a part of clinker by supplementary cementitious materials as slag allows reducing this impact. However, these materials have a slower hydration kinetics, which makes a mechanical, thermal or chemical activation necessary. Triethanolamine (TEA) is an amine commonly used as an accelerator, as it allows activating chemically the hydration. The mechanisms involved in this activation still need to be further investigated. Therefore, this study focuses on the interaction of TEA with slag blended cement. The slag blended cement paste was firstly studied without accelerator to highlight the impact of this mineral addition on the OPC reactivity. The effect of TEA on chemical reactivity was investigated by isothermal calorimetric measurements and scanning electron microscopy. The effects on the structural organization of the paste were highlighted by comparing particles size distributions and physicochemical stabilities of slightly diluted pastes. By combining the analysis of paste dispersion state and chemical reactivity, this study allowed identifying different modes of action of triethanolamine in slag blended cement in comparison with an OPC and a limestone blended cement used as references.

Synthesis and hydration of ye'elimite

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Synopsis: Ye'elimite-rich cements or calcium sulfoaluminate cements (CSA) are commercialized to prepare shrinkage compensation and self-stressing concretes. Moreover, CSA cements show environmentally friendly characteristics associated to their production, which include reduced CO_2 footprint. The expansive behavior of CSA cements is mainly controlled by ettringite amount, produced upon hydration of the key-phase, ye'elimite [$Ca_4(Al_6O_{12})SO_4$]. This paper presents, on one hand, the optimal conditions for the synthesis of highly pure ye'elimite by solid state reactions, and on the other hand, it shows a fundamental description of ye'elimite formation mechanisms. Another aspect of the study encompasses the influence of fineness and citric acid addition on ye'elimite phase dissolution, then on hydrates composition of lab made ye'elimite-rich cement. For the fineness effect study, a highly fine and pure ye'elimite was originally synthetized by sol-gel methods. Various experimental techniques were performed to conduct the different aspects of the present study, namely XRD-Quantitative Rietveld analysis, Thermal analysis (TGA, DTA and Dilatometry), SEM (BSE imaging and EDS mapping), BET analysis, PSD by laser diffraction, and Image analysis (2D porosity and 2D PSD).

Investigating Dual Sulfate Attack Mechanisms using Unidirectional Penetration Approach

Qiao Wang, William Wilson, and Karen Scrivener

Abstract: Sulfate attack is generally classified into chemical and physical sulfate attack. It is significantly different from lab ponding tests, instead, so called physical sulfate attack dominates in semi-immersed conditions which primarily occurred in field. However, due to its greater complexity, it has been strongly neglected and less investigated. This paper concerns developing a new test approach for physical sulfate attack degradation investigation and understanding the mechanisms behind it. The new test setup allowing unidirectional flow that enables to study it under controlled conditions (i.e., constant wicking action over fixed thickness with fixed relative humidity). To imitate the real field condition, sodium sulfate solution was used in contact with one side and refreshed every month, on the other side the relative humidity was controlled at 55 %. portland cement paste specimens were used with the proposed setup in the semi-immersed conditions to investigate the effect of w/c on sulfate attack. After several months of exposure to 30 g/L sulfate solution, the profile of sulfate ingression and phase assemblage was investigated by SEM-EDS and XRD, respectively. The lateral expansion and physical appearance of the samples were tracked over time. The results indicated physical and chemical sulfate attack occurred simultaneously on both sides of single sample and mechanisms and parameters involved were further discussed.

Keywords : Degradation ; Humidity ; Sulfate attack ; SEM ; Unidirectional approach

Prediction of time-to-corrosion cracking of reinforced concrete using deep learning approach

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Synopsis: This study presents an accurate corrosion prediction through an intelligent approach based on deep learning. The deep learning is used to predict the time-to-corrosion induced cover cracking in reinforced concrete elements exposed to chlorides ions. The key parameters taken into consideration include thickness, quality and condition of the concrete cover. The prediction performance of the deep learning model is compared against traditional machine learning approaches using neural network and genetic algorithms. Results show that the proposed approach provides better prediction with higher generalization ability. The efficiency of the method is validated by an accelerated corrosion test conducted on 91 and 182-day moist cured reinforced fly ash concrete samples with different water-to-binder ratios. The results are in agreement with the model predictions. They also show that using the proposed model for numerical investigations is very promising, particularly in extracting the effect of fly ash on reducing the extent of corrosion. Such an intelligent prediction will serve as an important input in order to assist in service life prediction of corroding reinforced concrete structures as well as repair evaluation.

Keywords: deep learning, fly ash concrete, genetic algorithm, time-to-corrosion cracking.

Environmental impact evaluation of a slag/fly ash-based strain hardening geopolymer composite (SHGC)

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Keywords: embodied energy, geopolymer, global warming potential, life cycle assessment, strain-hardening.

ABSTRACT

Strain-hardening geopolymer composite (SHGC) based on industrial wastes and by-products has emerged as a feasible alternative to strain-hardening cementitious composite (SHCC). Lately, a novel slag/fly ash-based SHGC with promising strain-hardening tensile performance and multiple cracking behavior has been successfully developed. However, its environmental impact with regards to its global warming potential and energy consumption remain to be evaluated.
This paper presents an evaluation and comparative study of the environmental impact factors of a newly developed slag/fly ash-based SHGC and three different types of conventional SHCC materials. The CO_2 equivalent global warming potential (GWP) and the embodied energy (EE) were calculated under a life cycle assessment scheme based on the product stage. SHGC has significant advantages in terms of the global warming potential (GWP) while maintaining comparable or lower embodied energy (EE) when compared with greener version of SHCC materials and typical SHCC material (ECC M45), respectively. It could be concluded that the newly developed slag/fly ash-based SHGC demonstrates a very promising LCA record while possessing excellent technical performance. Consequently, SHGC could serve as a promising alternative for SHCC materials with considerably lower environmental impact.

INTRODUCTION

Engineered cementitious composite (ECC) [1] is a strain-hardening cementitious composite (SHCC) with a micromechanics design basis [2]. However, high amount of normal Portland cement in SHCC makes it a high energy embedded product and increases the CO_2 emission, which negatively impacts its sustainability performance. Researchers have partially replaced cement with supplementary cementitious materials (SCMs) to improve the greenness of the material [3-5]. Another emerging solution involves the utilization of cement-free alkali-activated binder material to replace the traditional cementitious binder as the matrix in conventional SHCC In this case, a strain hardening geopolymer composite (SHGC) is prepared. The matrix used is alkali-activated materials (AAMs) including those classified as geopolymer, which are derived from the reaction of an alkali metal source (solid or dissolved) with a solid (alumino-)silicate powder [6, 7].

Several previous studies have successfully developed SHGC based on different solid precursors and microfibers. For instance, Ohno and Li studied the feasibility of strain hardening fly ash-based geopolymer composite and developed a type of SHGC based on fly ash and PVA fiber, i.e. an engineered geopolymer composite (EGC) [8, 9]. Nematollahi et al. developed SHGC using PVA fibers, including a fly ash-based EGC by heat curing [10, 11] and a slag/fly ash-based SHGC cured at ambient temperature [12]. Nematollahi et al also investigated the feasibility of using high modulus polyethylene (HMPE) fiber in a one-part SHGC [13]. Farooq et al investigated the tensile performance of several types of eco-friendly ductile geopolymer composite (EDGC) reinforced with different micro-fibers and strain hardening was achieved using PVA fiber [14]. Zhang et al. used a

An Approach to the Rheological Behavior of Cementitious Systems Blended with Calcined Clays and Superplasticizers

Ricarda Sposito, Marlene Schmid, Johann Plank and Karl-Christian Thienel

Synopsis: Calcined clays represent a promising future supplementary cementitious material (SCM) because of the worldwide availability of suitable clays and low material-related CO_2 emissions during calcination. The application of superplasticizers is inevitable for a secured workability of cementitious systems with calcined clays due to their specific chemophysical properties. For their prospective use as SCM, a sound knowledge is elementary about the interaction of calcined clays with superplasticizers depending on clay and polymer structure. An ordinary Portland cement is replaced by 20 wt% of calcined clays. Four different calcined materials are used: one calcined clay mixture, industrial metakaolin, a metaillite and a metamuscovite. One polycondensate and one polycarboxylate-based polymer, both industrial products, are chosen as superplasticizers. The required dosages are adjusted by the same slump flow, so a similar dispersing behavior for all systems is given immediately after water addition. Over a period of two hours after water addition, the rheological behavior is evaluated via mini slump test and by rotational viscometer. The impact of different velocities during measurements with the viscometer provides further information related to the viscosity of these systems.

Keywords: calcined clays, superplasticizers, rheology, viscosity, workability

Investigation on Microstructure of Cement Pastes Made with a By-product from Primary Aluminum Production

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Synopsis: Spent pot lining (SPL) is an industrial waste generated from aluminum electrolysis cells. LCLL-ash is the inert by-product coming from the treatment of the SPL refractory fraction at the SPL treatment plant (Jonquière, Canada). LCLL-ash has been ground to the fineness of the cement to substitute a part of cement in cement pastes. However, LCLL-ash contains higher contents of silica and alumina compared to Portland cement, which can affect the composition, the morphology and the mechanical properties of the binder hydrates (e.g. the Calcium-[Aluminum]-Silicate Hydrates, C-[A]-S-H) with an important effect on the durability. This paper focuses on the investigation of the microstructure and the mechanical properties of LCLL blended cement pastes by applying multiple techniques including scanning electron microscopy, X-ray diffraction, and microindentation at the level of the cement paste. The water-to-binder ratio (w/b) is fixed at 0.35. The effect of the different proportions of LCLL-ash on the microstructural and mechanical properties of blended cement pastes is presented and discussed with relation to the normal Portland cement paste.

KEYWORD: microstructure, micro-indentation, spent pot lining, SEM, XRD

BIOGRAPHIES

IMPROVING PERFORMANCE AND REDUCING THE CO_2 FOOTPRINT OF CONCRETE USING MULTIPLE APPROACHES

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Abstract

Approximately 90% of the carbon footprint from concrete production is from portland cement (assuming portland cement is used as the sole cementitious binder). Therefore to reduce its carbon footprint, the amount of Portland cement clinker needs to be reduced. There are different ways of doing this, including optimization of combined aggregate gradations, use of water reducing admixtures, use of portland-limestone cements (PLC), and use of supplementary cementitious materials (SCMs). All of these measures can be taken simultaneously, but there is also concern that extreme measures (such as high SCM replacement levels) will reduce the robustness of concrete to abuse during construction, resulting in lower durability. Durability is important to obtain long service lives of concrete structures, and has a large impact on their carbon footprint.

This paper includes discussion of how each these measures if used prudently, can achieve significant reductions in carbon footprint while simultaneously improving durability in aggressive exposure conditions.

Keywords: durability

Kaolinite Clay for Enhancing the Properties of Alkali-Activated Slag and Fly Ash Binders

Chathurani Chandrasiri, Zihui Li and Sulapha Peethamparan

Synopsis: The potential of using naturally occurring kaolinite clay as a low embodied energy fine material additive to enhance the performance of alkali-activated slag and fly ash binders are evaluated. The behavior of kaolinite clay (KC) containing systems was compared to that of the most popular nanoparticle, nao-silica (NS), incorporated binders. Kaolinite clay was added at 2 and 6 % by mass of the slag and fly ash to modify the early age hydration kinetics, strength development, and acid leaching resistance of alkali-activated binders. Sodium silicate solutions with a 1.5 silica modulus (SiO_2 /Na_2O) and a 2.5 or 5% Na_2O% (by mass of the binder) respectively for slag and fly ash mixtures were used. Similarly to the nano-silica containing systems, higher dosages of kaolinite clay significantly improved the compressive strength of alkali-activated binder systems. Kaolinite clay fine particles accelerated the early age hydration kinetics and modified the microstructure developments. The clay incorporated alkali-activated binders outperformed that of nano-silica incorporated binders in the acidic environment.

Keywords: acid leaching resistivity, alkali-activated slag/fly ash, compressive strength, kaolinite clay, nano-Silica.

Performance of NO_2 sequestered recycled concrete aggregates (NRCA) incorporated concrete: Influence of parent concrete properties

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Synopsis: The utilization of recycled concrete as an adsorbent to sequester NO_2 without additives or catalysts is an innovative, cost-effective, and sustainable approach to capture NO_2 from targeted industrial facilities. During NO_2 sequestration, alkaline products such as calcium hydroxide (CH) in the adhered old mortar of recycled concrete can react with NO_2 to form $Ca(NO_2)_2$ and $Ca(NO_3)_2$. Thus, the use of NO_2 sequestered recycled concrete aggregates (NRCA) as a constituent of concrete can be beneficial since $Ca(NO_2)_2$ and $Ca(NO_3)_2$-based chemical compounds are widely used as multi-functional admixtures for concrete applications. This study investigates the influence of the properties of the parent (demolished) concrete on the mechanical and durability performance of NRCA incorporated ordinary portland cement (OPC) concrete. Two types of recycled concrete aggregate (RCA) were derived from 2 and 20-year old concrete blocks to produce two types of NRCA−2-NRCA (2-year-old NRCA) and 20-NRCA (20-year-old NRCA) by exposing them to a humidified air/NO_2 mixture (at RH = 50% and 23±2°C) for two weeks. NRCA was used as a partial replacement for natural fine aggregate in fresh OPC mixtures at 20% and 40% rates by volume. The influence of NRCA on concrete compressive strength, porosity, and long-term chloride diffusion coefficients were assessed. In addition, open-circuit and potentiodynamic polarization tests were conducted to evaluate the resistance to chloride-induced corrosion of steel in concrete. Control test mixtures containing a commercially available $Ca(NO_2)_2$ based corrosion inhibitorwere also tested for comparison purposes. Both types of NRCA enhanced the mechanical and durability properties of concrete compared to control mixtures. Test mixtures containing 2-NRCA showed better resistance against chloride-induced corrosion than concrete with 20-NRCA.

Keywords: NO_2 sequestration, NO_2 sequestered recycled concrete aggregates (NRCA), chloride-induced corrosion, chloride diffusion

Influence of Quality of Recycled Concrete Aggregates Paste on the Internal Cure Phenomenon

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ABSTRACT:

Recent studies focused on the quality of the interfacial transition zone (ITZ) of ordinary concretes made from recycled aggregates (RA), without however focusing on High Performance Concretes (HPC).

This paper aims to formulate HPC from RA that are exclusively derived from concrete, whose composition is controlled. These concretes are made in a ready-mixed concrete plant and then undergo a crushing and riddling process to produce RA. Partially saturated gravels are substituted up to 100% in the HPC composition in order to accentuate internal cure phenomenon. This phenomenon was observed and demonstrated using a scanning electron microscope (SEM) in the low Water/Cement (W/C) paste up to a distance of 150 µm from the RA and compared by image processing, to a reference concrete made from natural aggregates (NA).

The comparison of the mechanical performances and the microscopic analysis of HPC show that the characteristics transfer of the RA seem to favor a hydration of the paste by a mechanism of desorption of their absorbed water, in a process of "internal cure". The internal cure appears optimal for concrete C60. In addition to this observation, there was an increase in the strength of the recycled HPCs compared to control natural-aggregate HPCs.

Keywords: Recycling, durability, interfacial transition zone, internal curing, High Performance Concrete

The Use of Ground Glass as a Pozzolan

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Synopsis: This paper presents data on the durability of concrete produced using ground glass as a pozzolan. Various sources of glass were used including soda glass, E-glass and Pyrex glass. All the materials showed excellent pozzolanic activity when ground to pass 75-microns. The use of ground glass resulted in substantial reductions in permeability and chloride penetrability, and improved resistance to sulfate attack. Air-entrained concrete containing glass showed good freeze-thaw resistance. Low alkali E-glass and borosilicate glass were effective in preventing deleterious expansion due to alkali-silica reaction (ASR). Bottle glass, which contains substantial amounts of alkali, was not efficacious with regards to ASR. The inclusion of bottle glass results in very substantial increases to the pore solution alkalinity and this can result in substantial increases in expansion in concrete containing reactive aggregate and low-alkali cement. It is shown that the accelerated mortar bar test is not suitable for evaluating the impact of high-alkali materials on ASR as the alkalis contributed by the cementing materials are released when the mortar bars are masked by the conditions of the test (first immersed in hot water and then in hot NaOH solution).

Keywords: ground glass, pozzolan, concrete, durability, alkali-silica reactivity.