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ABSTRACTS

(Alphabetical by Title)

An Engineering Approach for Permeability Assessment of Virtual Cement-based Materials

Kai Li, Piet Stroeven, Martijn Stroeven and Bert Sluys

A new approach to estimate the permeability of partially water-saturated virtual cement-based materials is outlined in this paper. Although the established full methodology (particle packing-hydration simulation-porosimetry analysis-permeability calculation) will provide satisfactory results in comparison with experimental data, it is extremely time-consuming and thus expensive. As an alternative, this paper presents an engineering approach to the aforementioned full methodology, while still maintaining reliability at an appropriate level. In the approach water permeability is correlated to the median pore size and the saturation degree of the specimen. A mathematical model is therefore proposed to approximate the water permeability using only these two parameters. A good agreement can be observed comparing the results obtained by the complete methodology and by the developed mathematical method. In this study, water/cement ratio, particle size range and hydration period were varied. Since pore connectivity and shape seem to have an influence on water permeability, their contributions are additionally considered to further improve the proposed method.

Approximation Assessment of Photocatalytic Air Cleaning Pavements

James E. Alleman, Joel K. Sikkema, Peter C. Taylor

This paper examines an approximation method to qualitatively assess the air-cleaning performance (i.e., specifically the elimination of aerial nitrogen oxide, NO, released within vehicular exhaust) by full-scale pavements which contain photo-catalytically reactive titanium dioxide under optimal conditions. Two hypothetical road configurations were considered using this method, including both a two-lane, low traffic density (i.e., 4,000 full-day AADT) and a four-lane, moderate traffic density (i.e., 10,000 full-day AADT) design. These options were then comparatively examined on the basis of expected European Union or United States vehicular emission levels. Using this paper's approximation method, and assuming best-case scenario conditions (i.e., original, un-aged, peak catalytic performance under optimal temperature, relative humidity, etc. conditions), day-time-only percentile removals in the ~mid-60% to ~90% range were predicted for EU two- and four-lane roadways with low to moderate traffic densities. In the case of similar US highway options, this method's approximated day-time-only elimination percentile results were lower than what was predicted for similar EU road options, with a range of ~30% to ~40%. These latter, lower US road approximations were believed to be related to higher expected US versus EU vehicle emission levels (i.e., by a factor of ~two- to ~three-fold for light and heavy duty vehicles).

Assessment of Resilience and Sustainability of Cement Based Facades for Mid-rise Commercial Buildings Exposed to Coastal and Seismic Hazards

Gonzalo Barluenga, Oluwateniola Ladipo, Georg Reichard and Roberto T. Leon

The aim of this study is to evaluate the most common Cement based facade (CBF) solutions for mid-rise office buildings considering their functional performance level, sustainability and resilience against coastal and seismic climatic hazards with data and examples taken from a literature review. CBF are classified considering the materials, the reinforcement and application (cast in place, prefabricated, multilayered, etc.), self-weight, functional/control layers' placement and interdependences with the structure. Then, CBF solutions are evaluated regarding their performance level (baseline, over-code and high performance) during "normal" operational conditions and amid climatic hazards. Sustainability analysis takes into account the manufacturing and construction impacts, the operational costs in normal conditions, durability aspects and the end of life conditions. Resilience assessment considers the effect of multiple coastal and seismic hazards, expected damages and recovery measures. A vulnerability analysis of the CBF types' expected damages, levels of damage regarding the baseline performance of functional layers, and functionality loss is carried out. The conclusions highlight the advantages of the different CBF types and the weaknesses that should be addressed to improve sustainability and resilience.

Behavior of Confined Recycled Aggregate Concrete

Mohamed Mahgoub

There are significant environmental benefits of recycling and reusing waste concrete as aggregate for structural concrete. The use of recycled aggregate concrete (RAC), however, is currently limited to non-structural applications such as road base and erosion control. Widespread application of RAC, such as

seismic applications, therefore requires an improved knowledge of the behavior under multi-axial state of stresses and development of behavioral models to describe the behavior under compression is essential. This paper presents part of the results of an extensive experimental investigation on mechanical properties of unreinforced RAC where the behavior under quasi-static axial loading was investigated and a one-of-a-kind stress-strain model was developed. It was observed that, quite similar to normal concrete, the stress-strain can be defined by a hyperbolic ascending-descending curve that is primarily a function of compressive strength, a straight descending branch which slope is a linear function of compressive strength followed by a sustaining branch. Development of this model is of great use in finite element simulation of RAC structural elements.

Case Study: Successful Market Place Implementation of More Sustainable Ready-Mixed Concrete using Portland-Limestone Cement

Tim Cost and Mark Stovall

The presented case study will be the experiences of a large ready-mixed concrete supplier which has successfully converted all concrete supplied by the company in a major metropolitan market to more sustainable mix designs using portland-limestone cement (PLC), with higher SCM replacement rates. All of the challenges mentioned have been overcome without exception, and the PLC concrete very well received in the market place. The new mix designs have implemented some of the findings of a recent research project of the Construction Materials Research Center at Mississippi State University, resulting in enhanced SCM interaction efficiency and related performance improvement. The favorable sustainability metrics have been accomplished without increased costs, and extended to all project types from residential concrete to highway bridges, parking garages, and other major building projects. Other benefits realized include notably improved finishability and appearance of formed and slipped surfaces. These benefits are now being extended to other areas as the company works to convert concrete production in other markets to PLC.

CO2-binding by Concrete Carbonation into LCA and EPD of Concrete Products

Anne Rønning, Kari-Anne Lyng and Christian J. Engelsen

The Environmental committee of Norwegian Concrete Association initiated in 2012 the project 'CO2-binding by concrete'. In the first part of the project, the objective was to estimate the total CO2-binding by the Norwegian concrete building stock in service life and in the recovery phase due to carbonation of concrete. Current standards for LCA allow for the inclusion of carbonation as long as it reflects the purpose and scope of the study and when the underlying report describes how CO2 uptake is estimated. This paper presents the results of including the CO2-binding into LCA for three concrete products; inner wall, hollow core slab and roof tiles. CO2 binding was included both in the user phase and at the end of life. The quantification of carbonation as a part of the GWP (global warming potential) was based upon the estimates for CO2-binding found in the first part of the project. The different products have different ability to carbonate. Roof tiles may fully carbonate during 30 years, while inner wall has a significant lower carbonation rate. Based upon the results from including CO2 uptake in LCA of concrete products, it is recommended to incorporate calculation methods in PCR for concrete products. To ensure transparency and comparability of EPDs, the PCR should be as specific as possible with respect to carbonation rate for specific products during the life cycle and not give a carbonation rate for concrete products in general.

Comparing Concrete EPDs: Motivation, Challenges and Next Steps

Kathrina Simonen and Barbara Rodriguez Droguett

Green building rating systems such as the USGBC's LEED V4 and Architecture 2030's Challenge for Products look to recognize and reward the use of products that demonstrate substantial reductions in environmental impacts when compared against an industry average. Architects and engineers are looking to use EPDs to select low impact concrete mixes and demonstrate a significant overall reduction to the material impacts of a buildings construction and achieve LEED V4 'whole building LCA' credits. All these initiatives presume that the results of the EPD are comparable, yet the comparability of EPDs depends upon the comparability of LCA calculation methods and the underlying LCA data. While the Carbon Leadership Forum PCR for concrete provides clarity on the LCA methods and references LCA datasets, there remain significant choices that must be made by the LCA practitioner in order to complete the LCA resulting in questionable comparability. This presentation will frame key drivers for comparability, outline the critical steps to perform an LCA, include the key features of the current PCR and give an overview of current concrete EPDs. Additionally, the presentation will address the status of current CLF efforts to improve the detail of LCA datasets referenced in the PCR as well as future work to develop globally aligned PCRs and be in conformance with the USGBC's 'enhanced EPD PCR requirements.'

Comparing the Mechanical and Fracture Properties of Concrete Made using Ordinary Portland Cement (OPC) and Calcium Silicate Cement (CSC)

Andrew Wiese, Jitendra Jain, and Jason Weiss

This paper compares the mechanical and fracture properties of concrete made using a typical ordinary portland cement (OPC) binder to that of concrete made using a calcium silicate cement (CSC) binder. The primary difference between the two binders is that the CSC binder carbonates to form a solid while the conventional OPC binder hydrates. One advantage of using concrete made with CSC rather than OPC is that the CSC can substantially reduce carbon emissions associated with construction. To compare performance of these two systems three tests were conducted. First, a displacement controlled compression test was performed to allow compressive strength, elastic modulus, and a stress strain diagram to be obtained. Second, a non-linear fracture test was performed to determine the critical stress intensity factor (a measure of toughness) and the critical crack tip opening displacement (a measure of the non-linear fracture process). In addition, a sustained-load fracture test was performed to ascertain the influence of moisture and loading rate on fracture properties. Results indicate that the samples made with OPC and CSC exhibit similar compressive and fracture properties. Fracture tests were performed at different crack mouth opening velocities and CSC showed similar performance at 1e-6m/s to 1e-7m/s and then a 20% decrease at velocities in the 1e-8m/s to 1e-9m/s range.

Context-dependence of Hazard Mitigation Strategies: Building Case Studies Around the US

Reed Miller, Jeremy Gregory and Randolph Kirchain

Building owners can decide to invest in hazard mitigation features or not by comparing that investment to their anticipated spending on hazard repairs across the building's lifespan. FEMA has developed a Benefit Cost Toolkit, which is designed to perform benefit cost analysis for applications submitted under FEMA's Hazard Mitigation Assistance Grant Programs. The free Toolkit has modules for earthquake, flood, hurricane, tornado, and wildfire. Many building types, defined by size, function, and construction, can be analyzed all across the country. The underlying model is based on a similar set of models used in the HAZUS software for city-scale analysis. Instead of analyzing a particular building, we utilize this Toolkit to compare the expected damage cost across different buildings utilizing different hazard mitigation strategies in a variety of locations. The recommendation to invest in hazard mitigation features will depend on the context.

Design and Application of the Precast Concrete Anchor Blocks for the TRNC Water Supply Project

Aydin Saglik and Emre Ozalp

This paper describes the challeges of a water supply project of Turkish Republic of Northern Cyprus (TRNC) from Turkey, in which high-density polyethylene (HDPE) pipes of total 80 km in length are to be used. These pipes are suspended 250 meters below the sea level by means of precast concrete anchor blocks that are positioned on the seabed at different depths, at a maximum depth of 1431 m. According to the specifications of the pre-cast concrete anchor blocks, the concrete should have a maximum w/c ratio of 0.35 and a minimum strength class of C40/50. Moreover, as this strength class of concrete has a high cement dosage and the smallest dimension of the anchor block is more than 1.0 m, the concrete should be treated as mass concrete. During the development of concrete mixture design, limestone aggregates with a maximum grain size of 19.1 mm were obtained from a local ready-mix concrete plant that has a production control certificate conforming to TS EN 206 standard. Moreover, from a cement factory nearby slag cement that conforms to EN 197-1 with a ground granulated blast furnace slag (ggbfs) content of at least 60% is obtained. Finally, a new generation of chemical admixture is utilized to produce self-compacting concrete. After developing the self-compacting concrete in the laboratory, anchor blocks were successfully produced.

Design of Sustainable and Resilient Concrete Mixtures via Multi-objective Optimization

Wil V. Srubar III and Joseph R. Kasprzyk

While conventional concrete mixture design methods employ a time-intensive, trial-and-error (bottom-up) approach – which ultimately yields acceptable (but non-optimal) designs of concrete mixtures, better-performing solutions, which simultaneously optimize competing objectives, can be obtained by employing a top-down many-objective evolutionary algorithm (MOEA) approach that leverages the capabilities of high-performance computing. In this paper, preliminary results from a MOEA-based concrete mixture design methodology using a specific case-study example, namely a specific application (1D reinforced concrete tilt-up wall) and location will be presented for walls that are designed to resist corrosion initiation and freeze-thaw damage for at least 100 years. The analysis included the following possible materials in the mixture design: (a) cement, (b) water, (c) fine aggregate, (d) coarse aggregate, (e) supplementary cementitious materials (SCMs) (i.e., fly ash, slag, silica fume, metakaolin), and (f) air. The locations (to calculate transportation costs), material costs, and lifecycle inventory (embodied energy) of each material was input into the Borg MOEA search algorithm, a state-of-the-art mathematical search tool.

Drying Shrinkage of Alkali Activated Cements and the Influence of Curing Conditions

Maryam Hojati, Farshad Rajabipour and Aleksandra Radlinska

This paper studied the drying shrinkage of four different AAC binders, all having a 28-day compressive strength greater than 30 MPa. These include an alkali activated class F fly ash (AAFA), an alkali activated slag (AAS), and two alkali activated F fly ash/slag blended binders with different proportions of slag and fly ash. All four binders, as well as a control OPC binder had the same (liquid/solid)vol and as such, same initial porosity. Drying shrinkage and mass loss of mini-prisms were monitored as a function of time at different relative humidities (RH). In addition, the effect of moist curing temperature (23oC vs. 60oC) on the subsequent drying shrinkage magnitude was evaluated. The results showed that all AAC binders cured at 23oC have high shrinkage in comparison with the OPC binder, and shrinkage increased with higher content of fly ash in the AAC. However, steam curing (60oC) had a significant impact on drying shrinkage and the steam cured AAFA binder showed the smallest shrinkage. The results also showed that shrinkage of AACs varied depending on the ambient RH. Interestingly, for AACs containing slag, the largest drying shrinkage was observed at 50% RH, with lower humidities resulting in lower shrinkage.

Early-Age Expansion of Wastepaper Sludge Ash: Reduction and Benefits

Ahmed Omran, Majid Jerban, Arezki Tagnet-Hamou

Wastepaper sludge ash (WSA) produced from combustion of wastepaper sludge, wood residue, and barks in combusted fluidized bed plant has recently shown potential applications as partial cement replacement in concrete; however, it exhibits expansion at early age. The current results showed the pre-wetting of WSA prior incorporating in concrete as a technique to reduce this expansion. The results conducted on mortar and concrete mixtures containing 20% pre-wetted WSA as cement replacement showed that the pre-wetting helps generating the expected disruptive hydration products before concrete setting, hence reducing the associated expansion problems and improved the strength. The current research also investigated the possibility of reducing the autogenous shrinkage of HPC by using the WSA without any treatments as well as pellets made from the WSA with particle sizes from 1-20 mm. The natural sand was replaced by 1-5 mm pellets and coarse aggregate by 5-20 mm pallets at rates up to 40% in addition to various combinations. The results showed higher early expansion and consequently reduction in the net deformation resulted from the autogenous shrinkage when replacing the natural sand and aggregate by WSA pellets. The drying shrinkage was also reduced especially with the 1-5 mm pellets.

Ecocrete-Xtreme : Holistic Solution for Concrete Sustainability

Olafur Wallevik, Thordur Kristjansson, Wassim Mansour and Fouad Yazbeck

EcoCrete-Xtreme is a state-of-the-art robust self-consolidating concrete (SCC) manufactured with both extremely low cement and cementitious materials contents (less than 80Kg of cement out of less than 220Kg of total cementitious). This offers a significant reduction in CO2 of up to 75% compared to any other SCC products. This mix is designed to have superior rheological properties making it easy to flow and fill complex forms in record time without any need for the consolidation process normally required for conventional concrete. EcoCrete-Xtreme is extremely durable compared to other concrete products. Its service life is predicted to be more than 150 years for structures exposed to a marine environment, knowing that conventional concrete would generally have around 15 years of service life in such harsh environment. EcoCrete Xtreme is a cost effective solution, especially when considering the reduced workforce, the time needed to place this concrete and the fact that this concrete would not require any repair work during its extended service life. This presentation will brief the properties of EcoCrete-Xtreme with emphasis on the design stages of this concrete product.

Effect of Fibres on High Volume Fly Ash Self Compacting Concrete

Chetan Modhera and Ujjaval Shah

The research reported here deals with the impact of fibre on high volume fly ash self-compacting concrete (HFSCC) performance on its properties both in fresh and hardened conditions. The properties of fresh fibre reinforced HFSCC has been investigated as per the available European Standard (EFNARC) in three categories: flowability, resistance to segregation and flowability of fresh concrete. For the hardened part, standard properties of HFSCC with fibres, such as compressive strength, flexural strength and split tensile strength at 7days, 28days and 56days, have been conducted. Three types of fibres (Polypropylene, carbon and hybrid) were incorporated with dosage of each up to 0.3% by volume of concrete in HFSCC; the reduction in slump flow from 40% to 47% was found. It was found most satisfactory for 0.1% by volume of concrete; and was consistent with the EFNARC requirements. In this work, fibres were added individually and as combination ("hybrid") up to 0.3% by volume. In all cases, 0.1% polypropylene fibre dosage was observed to give the best results among all other combinations.

Effect of Recycled Concrete Aggregates Properties on Long Term Shrinkage and Cracking

Ahmed Z. Bendimerad, Hamza Samouh, Emmanuel Roziere and Ahmed Loukili

In France, 300 million tons of building wastes are produced per year; only a part is used for recycled concrete, mainly for road works. The influence of recycled concrete aggregates on short-term and long-term behavior of concrete is significant. Particle size distribution, shape, porosity (measured as water absorption), and initial water saturation affects workability, plastic stage properties, setting and hardening, strength, durability and time-dependent behavior – shrinkage and creep. Generally, the absorption at 24 hours is taken as a reference to assess effective water and added water contents. However, setting of cement paste may occur before the full absorption of water by aggregates. Thus, the actual water content of cement paste is not the theoretical content and the water/cement ratio is modified. Therefore, the behavior of concrete is influenced by the initial water saturation of aggregates.

Effect of Recycled Fine Aggregate on Mortar Properties

Xinsheng Wu, Yue Hou, Zhi Ge and Renjuan Sun

This paper studied the effect of recycled fine aggregate (RFA) on the properties of mortar, including flowability, flexural strength, compressive strength, internal relative humidity, and autogenous shrinkage. The absorption/desorption properties of RFA were measured. Aggregate was soaked in water for different time to achieve different moisture content. In this study, three levels of water-cement ratios (0.28, 0.30, and 0.32), four levels of replacement (0, 30%, 60%, 100%) of RFA, and five soaking times (0, 2h, 5h, 10h, 24h) were adopted. The results indicate that RFA has a 24h absorption of 7%. The desorption behavior was affected by the environment relative humidity. Replacing river sand with RFA reduced the flowability. The compressive strength increased with reduction of water-cement ratio and decreased with the increase of replacement level of RFA. The soaking time had non-significant influences on compressive strength. All of the results show that RFA had little or no influences on the flexural strength.

Effect of Type of Fibers and Fiber Volume on Flexural Performance of Super-Workable Concrete

Ahmed Abdelrazik and Kamal H. Khayat

This presentation compares the enhancement of the mechanical properties and the crack resistance of super-workable concrete (SWC) and fiber-reinforced super-workable concrete (FR-SWC). The mechanical properties and crack resistance enhancement measures included the use of fibers at two different fiber volumes 0.5% and 0.75%. Test results revealed that the FR-SWC containing hybrid fibers (92% steel and 8% polypropylene fibers) of low fiber factor (L/D) of 34 exhibit lower flow ability and passing ability than similar mixtures made with ST1 fibers of higher fiber factor of 80. The SWC made with the 5D steel fibers at 0.75% had the highest compressive strength. The SWC made with the ST1 steel fibers with fiber volume of 0.75% showed the highest splitting tensile strength. The combination of micro and macro steel fibers yielded better flexural strength and flexural toughness compared to those of the macro steel fibers.

Effect of Using 'Chat' on Mechanical Properties of Concrete

Goli Nossoni and Feksi Basha

This research is aimed at producing an environmentally friendly concrete using the industrial waste product "chat" as a fine or coarse aggregate in concrete. Chat is a byproduct of mining and milling operations in lead and zinc mines. Federal agencies have suggested that chat be used in concrete and asphalt as aggregates for environmental protection purposes since it contains varying concentrations of lead. Observations from past research has shown that tailings used as aggregate substitutes generally help to increase the overall compressive strength of concrete. It has also been observed that tailings can reduce the level of chloride penetration in concrete. Concrete containing different percentages by weight of coarse aggregate and fine aggregate replaced by chat was mixed with a water to cement ratio of 0.4. The unconfined compression strength of each mix was determined at 28 days. The results indicate that the compressive strength of concrete is not reduced when chat is used in concrete and is in fact increased slightly when 50% of the coarse aggregate is

replaced by chat. Rapid chloride migration and lead leachability tests are being conducted at present to determine the chloride penetration resistance and safety of this sustainable concrete.

Effect of using Mineral Admixture on the Effiiciency of Bacteria Encapsulated Self-healing Concrete

Goli Nossoni and Daniel Hussey

The calcium content is an important factor in bacteria-based self-healing concrete. In general, mineral admixtures have a lower calcium content than ordinary portland cement. ACI recommends that 15 to 25% of Portland cement be replaced by fly ash type F, which has low calcium content (less than 20%), and 20 to 35% by fly ash type C, which has a higher calcium content (more than 20%). This paper discusses the effect of replacing different amounts of Portland cement by fly ash on the healing rate of the self-healing concrete. Cylinders were produced with concrete mixture where 0%, 5%, 10%, 15% and 20% of cement was replaced by fly ash. The samples were cut into one-inch thick disks, cracked, and allowed to heal by exposing the samples to fresh water. Initial results indicate that healing occurs when 20% of cement is replaced by fly ash. However, these samples were cut and cracked at 4 weeks. To ensure that the healing effects were not a result of continued hydration of fly ash, additional samples were allowed to cure for 7 weeks and the widths of the cracks are being monitored for 14 weeks. The findings from this work will be reported.

Efficacy of Bacteria Encapsulated Self-healing Concrete Exposed to Salt Water and Freeze-Thaw Cycling

Goli Nossoni, Daniel Hussey and Marisa Budziszewski

The formation of micro-cracks in concrete is unavoidable. Researchers have been investigating techniques that can repair cracks autogenously. One technique uses a specific type of bacteria within the concrete to produce minerals and effectively seal cracks. To produce the self-healing concrete, a specific type of endospore forming bacteria were encapsulated in a lightweight aggregate. The aggregate was also impregnated with calcium lactate to provide a mineral food supply for the bacteria. The metabolic process of the bacteria converts the calcium lactate into calcium carbonate. Research has shown that the minerals produced can reduce crack widths, and fully seal micro-cracks in the concrete. In this research, concrete was mixed with a self-healing bacterial agent. After 28 days of curing, samples were cut into one-inch thick disks and the disks were cracked. Multiple samples were then exposed to different environmental conditions. The marine environment was simulated by placing samples in a 3.5% saltwater solution. The freeze-thaw cycles were simulated by having samples submerged in water and placed in a freezer and subjected to 6 hours of freezing and 18 hours of thawing. The widths of cracks were monitored under a microscope for 18 weeks. The results suggest that the bacteria could remain effective in salt water environments, but cold temperatures would limit their healing properties

Evaluating the Albedo-induced Radiative Forcing and CO2 Equivalence Savings: A Case Study on Reflective Pavements in Selected U.S. Urban Areas

Xin Xu, Jeremy Gregory and Randolph Kirchain

There is a growing interest in developing cool pavement strategies to mitigate pavement's impact on the global warming in recent years. One of the mitigation strategies is by increasing the solar reflectance (or albedo) of the pavement surface, which directly contributes to global cooling by adjusting radiative forcing and potentially reduces the energy demand in the urban areas. In this paper, the radiative energy budgets in four urban areas are investigated based on the data derived from NASA satellite measurements and climate simulations. The radiative forcing (RF) due to the change of urban surface albedo as a result of reflective pavements is estimated using a simplified engineering model. The carbon dioxide (CO2) equivalence savings are also calculated with reference to the 100-year global warming potential of CO2. Results show that the implementation of reflective pavement has a great potential to reduce global warming. The CO2 reduction is significant in the urban areas but also affects the surrounding regions to some extent. In the end, we recommend using a climate model incorporating site-specific information that enables the visualization of the outputs through spatial maps. The results from this work would be useful for guiding the implementation of the cool pavement strategies.

Factors Affecting Embodied Carbon Comparison of Timber and Concrete

Frances Yang, Hans-Erik Blomgren and Lauren Wingo

Timber has a complex carbon cycle, starting with the sequestration of carbon during the growth phase, followed by the emission of carbon during the product, construction, use, and end-of-life stages. While timber is often perceived as having a lesser embodied environmental impact compared to conventional structural materials, several factors have a large impact on the embodied carbon content of timber. In this case study, a high-rise heavy timber residential building design is compared to a conventional post-tensioned concrete design. The results indicate that the timber design does not inherently have a lower embodied carbon impact and instead demonstrates a reduced embodied carbon impact only if specific strategies are implemented.

Field Trials with Concrete Incorporating Biomass Fly Ash

Ahmed Omran, Ailing Xie, Tatyana Davidenko and Arezki Tagnit-Hamou

Given the potential reduced availability of traditional fly ash in near future due to the strategy of closing the coal-based electricity power plants all over the world, biomass fly ash the by-product of combustion of de-inking sludge, bark, and residues of woods in fluidized-bed system can be an alternative. After successful use of biomass fly ash as partial replacement of cement in concrete in laboratory, the current research presents the performance of using the biomass in concrete structures in field. The biomass ash is used to replace 15%, 20%, and 25% of cement in normal and fiber reinforced concrete used for casting external and internal slabs as well as sidewalks. The results showed the possibility of using biomass fly ash as a cement replacement with a higher mechanical strength than the reference concrete with only Portland cement especially at age beyond 91 days. The concrete incorporated 20% biomass fly ash decreased the permeability, and resulted in excellent resistances to freezing-thawing and de-icing salt scaling deteriorations.

Going Green on Campus with Pervious Concrete Pavement

Marleisa Arocho and Sangchul Hwang

In an effort to go green on the University of Puerto Rico at Mayagüez campus with respect to stormwater management and to provide enhanced livability and safety to the students, a pervious concrete bicycle parking area (490 ft2) is currently under construction. To make the pervious concrete pavement more sustainable and economical in line with waste-to-resource, a locally available industrial byproduct, coal fly ash, will be used to replace cement by 21.4% based on the lab-scale statistical optimization study. In fact, pervious fly ash concrete pavement containing coal fly ash showed an enhanced compressive strength while possessing a desired permeability and a superior performance for reduction of fecal coliforms and phosphorus in the previous studies. The pervious concrete to be used for the bicycle parking area is predicted to have a 28-day compressive strength at 15 MPa and a permeability of 4.5 mm/s. It will be placed at a depth of 6" on the top of 12" gravel storage layer. Runoff quantity and water quality will be compared before and after the implementation.

Green Chemistry of Concrete Recycling

Jialai Wang, Liang Wang and Peiyuan Chen

This study proposes a green routine to recycle concrete for multiple value added products. Old (demolished/waste) concrete is first treated with acetic acid solution, instead of strong acids to minimize the potential health hazard. Acetic acid can dissolve calcium ions from hardened concrete and weaken the cement paste on the old concrete. The loosed cement paste is then removed through mechanical rubbing. In this way, the treated old concrete has much lower waste absorption and weaker cement paste. Once used as aggregate in new concrete, the treated old concrete can increase the compressive strength of the concrete at 28 days by 25%. The waste solution of the acetic acid treatment, which is rich in calcium and acetate ions, is then treated by passing through dioxide. This process not only produces high value products such as vaterite, but also stores carbon dioxide permanently in calcium carbonate. Partial acetic acid consumed during treating the old concrete can also be regenerated by this carbonation process.

Guide to Material Ingredient Disclosure for Concrete

Tien Peng

The changes in LEED v4 were introduced to push project teams to meet more stringent requirements and to focus on building material transparency. The new Material and Resources (MR) Material Ingredients credit asks manufacturers to fully report all ingredients and known hazards in their products. The challenge to concrete manufacturers is to make this credit achievable to LEED project teams without disclosing potential proprietary information. Moreover, there is concern that ingredient disclosure can be misconstrued when few specifiers understand chemical components. NRMCA with funding from the Ready Mixed Research and Education Foundation has developed the Material Ingredient Reporting Guidance for concrete which helps producers and their supply chain take the first steps to meeting the new disclosure requirements, without sacrificing intellectual property. The Guide addresses industry disclosure strategy using the Health Product Declaration open standard as well as other USGBC accepted formats.

How Concrete Quality Impacts Sustainability

Karthik Obla

This presentation will make a compelling case that improvement in quality will lead to better sustainability and cost savings. The role of concrete mixture optimization in achieving better sustainability and cost savings will also be examined. Quality measurement tools and NRMCA resources for improving quality will be highlighted.

Improving Concrete Sustainability through Design for Durability

R. Douglas Hooton and Majella Anson-Cartwright

There are many ways to reduce the initial carbon footprint of concrete including reduction in its Portland cement clinker content by methods including: (a) optimization of total aggregate gradations, (b) use of water-reducing admixtures, (c) intergrinding clinker with limestone, and (d) use of supplementary cementitious materials (SCMs). However, the most effective way to improve the life-cycle sustainability of concrete structures is by making them last longer through design for durability, and by minimization of construction defects. In almost every case, durable concretes will include many of the above listed approaches, but from a design approach, the emphasis needs to be on durability. Durability design includes more than the selection of concrete materials and mix proportions. It also requires that construction detailing, temperature control, adequate compaction, protection of fresh concrete, and curing be detailed in the specification and that inspection and testing be carried out to ensure that the specifications are being followed.

Innovative Sample Design for Corrosion Rate Measurements in Carbonated Blended Concrete

Matteo Stefanoni, Ueli Angst and Bernhard Elsener

Lowering the clinker content of concrete using high volumes of SCMs can contribute significantly to reduce CO2 emissions of building materials. However, uncertainty about durability, especially carbonation induced corrosion of reinforcement, is the main factor limiting the practical use of these blended cements. Data so far can be obtained only with very time consuming tests due to the sample size of standard concrete samples and the slow carbonation process. In this paper an innovative experimental setup is presented that overcomes these limitations. The setup consists in miniaturised thin samples with a size of 80 x 80 x 6 mm, thus with an effective carbonation depth of only 3 mm. For these thin samples the time to full carbonation is quite short and no high CO2 concentrations are necessary. In the samples five steel wires, a reference electrode (Ag/AgCl) and a stainless steel grid counter electrode allow any kind of electrochemical measurements (potential, linear polarization resistance, electrochemical impedance, resistivity, etc.). Additional measurements are performed to characterize the cement paste matrix (porosity, pore size distribution) and the interface steel/cement paste matrix. Our preliminary results show that these samples allow any kind of electrochemical measurements can be performed – thus the study of corrosion and related influencing parameters, in homogenous carbonated conditions, is possible within a short time scale.

In-situ Production of Nano/Micro Particles in Fresh Concrete

Jialai Wang and Xin Qian

This study proposes a novel method to in-situ produce nanoparticles in fresh concrete using carbon dioxide gas. The new method can significantly enhance

the sustainability of concrete through permanently storing carbon dioxide in concrete and increasing the performance of concrete. By using this method, calcium carbonate nanoparticles coated with a thin layer of silica can be in-situ produced in fresh concrete, which can not only serves as ideal nucleating sites for the hydration products of ordinary Portland cement, but also densifies the microstructure of the concrete. Synergistic effects between CO2 and cementitious material are also triggered by this method: 1) calcium carbonate produced by this method transforms from amorphous or metastable phase to stable phase so that calcium carbonate also functions as binding phase in concrete; and 2) calcium carbonate produced by this method changes the mineralogy of the hydrated cement to produce larger volume of hydration minerals and thereby to reduce porosity of the concrete or harder crystal to strengthen the concrete. Experimental studies show strength of concrete can be significantly increased by this method.

Internal Curing using Perforated Cenospheres

Fengjuan Liu and Jialai Wang

This study proposes to use perforated cenospheres as internal curing agent for concrete structures. A low-cost chemical etching method is used to remove the glass-crystalline nanosize film cover the shell of cenospheres so that inner volume of the cenosphere is available to water. The new internal curing agent is not only low-cost, but also provide better internal curing results. This internal curing agent can find many applications on highway structures such as bridge decks and pavements. By using this internal curing agent, the early-age shrinkage and shrinkage cracking of concrete can be reduced or eliminated, and therefore the permeability of concrete is reduced, too. As a result, the service life of concrete structures can be significantly increased and the life-cycle cost can be significantly reduced.

Investigation of Rheological Behaviour of Self-Compacting Marbled Paste

F. Messaoudi, O. Haddad, R. Bouras, M. Sonebi and S. Kaci

Mineral and organic additives are two essential components in the formulation of self-compacting concrete, which are the two components that govern the rheological behaviour of concrete. Mineral additives are introduced into the concrete to improve their rheological behaviour in the fresh state, but also to participate in the mechanical properties and durability of concrete, especially in cases where they are active. In this study, two series of tests were performed on the self-compacting cement pastes composed of additions and waste marble as a mineral addition. The first series of tests is to determine the spread of these pastes using a mini cone, the second series is to determine the rheological parameters of the same pastes namely the yield stress and plastic viscosity using the Haake rheometer RheoStress 1 a correlation between the results obtained in the tests and of spreading the shear threshold of the cement paste mottled different considering the influence of superplasticizers and viscosity agent) is given.

Is the Concrete Profession Ready for Peformance Specifications that Provide an Alternative to Prescriptive w/c and Air Content Requirements?

Jason Weiss

This paper presents research that is intended to provide an alternative to simple prescription of w/c and fresh air contents to provide durability. The work will discuss that while w/c and air specifications have been very beneficial for nearly a century, the time may have arrived to consider an alternative specification approach. The work discusses the use of simple 15 second test to determine the formation factor to describe transport. The work also discusses the use of a simple test to determine the resistance to freezing and deicing salts. The presentation will end with example language that may be able to be used as an alternative to current ACI and DOT specification language.

Jobsite Experiences from a Tunnel Restoration with Freeze-Thaw-Resistant SCC

Florian V. Mueller

Experiences are shared from a jobsite with medium flowable self-consolidating concrete, i.e. class SF2 according to EN 206-9, containing air to ensure freeze-thaw-resistance, and aggregate size up to 16 mm. After difficulties in obtaining a homogenous hardened concrete while focusing on the slump flow value alone, standard fresh concrete tests were performed, revealing the missing balance of flowability (yield stress or slump flow value) and inner resistance against dynamic segregation in terms of plastic viscosity. The application of the rheograph, approximately transformed in terms of standard one-point-rheology results, such as slump flow value, time to reach a spread of 500 mm, or V-funnel flow time, correlated very well with experiences on the jobsite. Here, some mixtures resulted in severely segregated surfaces in hardened concrete, while others did not achieved sufficient self-compactability in the fresh state and the form filling had to be supported. The example reflects the responsibilities the involved parties (i.e. planning engineers, contractors, and concrete producers) have, when SCC is planned to be used at a jobsite.

Life Cycle Approach to Green Concrete

Lionel Lemay

With greater emphasis placed on sustainability in recent years, design professionals, contractors and product manufacturers are faced with the challenge of meeting traditional design criteria in addition to evolving green building objectives. Many project specifications provide prescriptive criteria such as minimum SCM content or maximum cement content with the objective of minimizing environmental footprint of concrete. The National Ready Mixed Concrete Association recognized that it would be advantageous to provide performance-based alternatives to concrete contractors and producers for meeting green building criteria for reducing environmental footprint of concrete. This presentation will provide guidance on how concrete performance can be improved while lowering environmental footprint by using life cycle assessment methodologies, product specific environmental product declarations (EPD) and establishing industry benchmarks through an industry-wide EPD.

Managing Returned Concrete – A new ASTM Specification

Colin Lobo

Returned concrete averages about 2% of the ready mixed concrete produced. The most economical and environmentally sound option for concrete producers is to reuse returned concrete in its fresh state for alternate customers. ASTM C1798 is a recently approved specification that addresses the reuse

of fresh concrete by adding new materials for a new batch of concrete. This presentation will discuss some of the effects on quality and discuss the provisions in the new specification.

Material Flow Analysis of the Concrete Chain in the Netherlands

Mingming Hu, René Kleijn, Jeroen Guinée and Francesco Di Maio

The Dutch concrete industry is targeting on a 100% sustainable concrete value chain by 2050. From a mass balance point of view, this is really challenging, innovations are needed to shift concrete down-cycling to recycling for a sustainable concrete value chain in the coming decade. The government statistics of the Netherlands predicts that whereas nearly 100% of the end-of-life (EOL) concrete (ca 10 million tons) is absorbed by the Dutch road sector today, this number will have dropped to below 40% by 2025, creating a surplus of EOL concrete for the Netherlands of about 15 million tons per year. This paper presents a mass flow analysis of the concrete value chain in the Netherlands in the year of 2005 and the year of 2025, considering different technological and social-economic development scenarios. The main findings are that cost effective recycling is essential for promoting recycling as opposed to down cycling practices of the EOL concrete in the Netherlands. If widely implemented, the cost effective technology can increase recycling rates in the Netherlands from current rates of 8% to 40% by 2025. If there are no developments in the current recycling technology, the use of secondary aggregates in Dutch concrete manufacturing will remain below 6%.

Mechanical Properties of Pumpable Steel Fiber Reinforced Lightweight Concrete for Application in Load-bearing Walls

Florian Junker, Torsten Mueller, Hubertus Kieslich and Klaus Holschemacher

Using lightweight concrete enables decrease in dead load and thermal conductivity in case of manufacture of concrete walls. With addition of steel fibers to concrete, its properties are altered from brittle to ductile, so the use of additional mesh reinforcement can be avoided. This study is aimed at investigating the effect of change in steel fiber content on the properties of steel fiber reinforced lightweight concrete (SFRLC). Flow table test was conducted to find the workability of fresh concrete mixture regarding the pumpability. Further compressive strength, modulus of elasticity, flexural strength and oven-dry density were tested. Four mixes of SFRLC with two different oven-dry densities (< 1200 kg/m³ and < 1600 kg/m³) and two different fiber contents (0.5 % and 1.0 %) were prepared to study the change in its fresh and hardened properties. The results of this study show a possibility to produce a pumpable, high ductile, lightweight concrete for load-bearing walls.

Microbial Challenges for Long-lived Concrete Formulations

Don Satchell

By incorporating a biocide additive into the concrete matrix, there is the potential for providing durable antimicrobial efficacy to the material. In turn, additives support antimicrobial efficacy against selected organisms such a fungi and bacteria. The intended use would be to provide longer life expectancy for concrete material by allowing the material to better withstand environmental conditions and organisms associated with microbial induced corrosion (MIC). Selection of the appropriate antimicrobial can depend on several factors, as well as the application of the additive to the material. To overcome the challenges associated with the development of antimicrobial concrete, a modified method for accelerated aging of concrete and testing has been developed. The method is based on the ISO -22196 bacterial test method and provides a relatively fast and efficient method for determining antimicrobial activity of a treated concrete or stone aggregate material. The method can also be used in the assessment of a range of microorganisms include bacteria, fungi and algae providing a template for the testing of antimicrobial additives to these materials as needed for replicating a given environmental condition.

Micro-proportioning of SCC with Crushed Aggregate: PART I Filler Particle Characterization and Properties

Rolands Cepuritis, Stefan Jacobsen, Sverre Smeplass, Ernst Mørtsell and Børge J. Wigum

In concrete micro-proportioning, the fine particle size distribution (PSD) is adjusted by controlling and varying the PSD of different aggregate fine fractions smaller than about 0.125-0.250 mm (also cement and pozzolana may of course be included). It has been performed concrete micro-proportioning with the fine part of the crushed sand (≤ 0.250 mm) divided into several fractions by air classification that were re-combined to obtain a desired PSD of the fines. In practice this can be done either at the RMC plant or at the crushed aggregate quarry. Here in PART I it is presented the particle properties of crushed sand made from rock types of 10 different quarries in Norway. The 10 materials included igneous (intrusive and extrusive), metamorphic and sedimentary rocks that are both monomineralic and polymineralic. The results presented here include X-ray micro-computed tomography (μCT), coupled with spherical harmonic (SH) analysis to mathematically describe the full 3-D shape of particles and investigations with the 2-D Dynamic Image Analysis (DIA) approach as an alternative fast and industrial method for shape measurements. The study also investigates the applicability of methods, such as laser diffraction, X-ray sedimentation and BET for PSD and specific surface measurements of the crushed aggregate fines.

Microstructural Characteristic of Alkali-activated Fly Ash Exposed to CO2-rich Environment

S.M. Park, J.G. Jang, G.M. Kim and H.K. Lee

Previous studies on alkali-activated fly ash were dedicated to provide a basis of the material as a construction material with a lower low CO2 footprint in place of Portland cement. A sufficient level of understanding was acquired, particularly the chemistry of geopolymer, a zeolite precursor, is now well-defined. An emphasis is given in the evaluation of its performance and stability under various aggressive conditions in recent studies. The present study investigates the microstructural characteristics of alkali-activated fly ash exposed to CO2-rich environment. This study provides a summary a series of experimental study and multi-technical analysis results displayed in [1]. The result of this study may provide important implications to understand the interaction between the alkali-activated fly ash under aggressive conditions involving CO2.

Minimizing Paste Content in Concrete Using Limestone Powders - Demonstration Mixtures

Dale P. Bentz, Scott Z. Jones and Didier Lootens

This presentation outlines an approach to replacing not only cement powder, but effectively cement paste consisting of the cement and water, with

appropriately sized limestone powder(s). Pastes, mortars, and concretes are each formulated with limestone powder replacement for a portion of their cement paste component. For these mixture modifications, the water-to-cement ratio (w/c) is maintained at or above 0.4 to provide sufficient water to react with all of the cement, so that none of this most costly component of cement-based materials goes to waste. Meanwhile, the water-to-solids ratio (w/s) is reduced to a value in the vicinity of 0.25 to 0.30 in order to maximize the limestone powder replacement level while still providing sufficient flow and rheology, by using reasonable dosages of high range water reducing admixtures. The fresh, early age, and 28 d performance properties of these high volume limestone powder (HVLP) mixtures are contrasted with a w/c=0.4 ordinary portland cement (OPC) paste, mortar, or concrete reference, respectively. In general, the properties and performance of these more sustainable mixtures are similar or even superior, suggesting that these new paradigm HVLP concretes could be readily substituted for existing conventional OPC mixtures.

Mitigating Drying Shrinkage of Alkali-activated Slag: A Closer Look at the Influence of Curing Condition and Expansive Reaction

Hailong Ye and Aleksandra Radlinska

In this work, four shrinkage mitigation strategies in alkali-activated slag (AAS) were evaluated, to better understand shrinkage mitigation mechanisms in AAS binders. Specifically, steam curing, long-term moisture curing, sulfate-enrichment, and calcium-enrichment were implemented to potentially mitigate shrinkage. The results show that steam and long-term moisture curing can considerably reduce shrinkage, likely through improving the stability of the calcium-alumina-silicate-hydrate (C-A-S-H) in AAS. However, mitigating shrinkage through early-age expansion is less effective, since the dominating component of drying shrinkage in AAS is due to the long-term viscous deformation of glassy C-A-S-H.

Multi-Functional Concrete Inlays for Pavement Preservation and Sustainability

Sushobhan Sen, Daniel King and Jeffery Roesler

Pavement preservation is increasingly being seen as an efficient way of extending the service life of pavements while also efficiently extending available funding resources. Among the options for using concrete in pavement preservation, Flowable Fibrous Concrete (FFC), which combines principles of SCC with fibers for building thin inlays, is an attractive option. When combined with titanium dioxide (TiO2) white cement, this FFC can also improve other pavement sustainability metrics. A new method to determine the albedo of a TiO2 mixture for FFC was developed and found to be 0.54. Microscale modeling showed that surface albedo as well as pavement structure strongly impacts canopy layer heat islands. In addition, the nitrogen oxides (NOx) removal potential of several TiO2 mixes was evaluated using bench-scale testing for paste and mortar samples. High-albedo specimens showed higher potential for NOx removal, although this decreased with carbonation. Addition of fly ash was found to limit this decrease. Therefore, it is possible to develop an optimal mix to meet strength requirements while also mitigating pollutants and heat islands.

New Permeability Reducing Admixture for Sustainable Concrete

Giorgio Ferrari, Vincenzo Russo, Danilo Passalacqua, Gilberto Artioli and Luca Valentini

This presentation describes a new permeability reducing admixture able to effectively reduce the movement of water under hydrostatic head pressure. The new inorganic polymer truly catalyzes the fast nucleation of CSH from hydrating cement, not only onto the surface of cement grains but also the homogeneous nucleation in the capillary pores of hydrating cement paste. The crystallization of CSH in the capillary pores refines the porosity of cement paste of the whole concrete and significantly increases the resistance to water penetration under pressure. The mechanism of homogeneous crystallization of CSH in the capillary pores was demonstrated by Synchrotron XRD micro-Tomography (XRD-μT) and by Scanning Electron Microscope (SEM) investigations. The effectiveness of the new admixture was verified by testing the permeability of concrete by European Standard EN 12390-8 by exposing the concrete specimens to a water pressure of 0.5 MPa for 72 hours and then measuring the water penetration. The results indicated that the new admixture is highly effective in reducing the penetration of water, compared to a reference concrete with the same W/C. The new admixture increases the early strength development of concrete and can be used in conjunction with WR and HRWR to produce concrete with outstanding mechanical performances and durability.

Obtaining Optimum Workability using Rice Husk Ash in a Modified Cementitious System

Nsesheye Susan Msinjili, Wolfram Schmidt and Andreas Rogge

In many developing countries in sub-Saharan Africa (SSA), agriculture is the leading economic sector. Generally, agricultural by-products are eco-friendly and have no further use for the environment. These by-products (baggase, cassava peels and rice husks) are mainly not the materials of discussion in this current day and age and especially in the northern hemisphere, where the majority of concrete technology originates. Hence, it is inevitable to consider other resources in concrete sustainability for SSA. Nevertheless, optimisation of these resources in concrete can only function with a clear understanding of the reactivity of the materials and its interaction and mechanism to adopt similar and workable properties as a normal and high performance cementitious system. This paper addresses rice husk ash (RHA) as a main SCM in a modified cementitious system and observes its performance in mortar. To achieve optimum workability, a look into RHA interaction with plasticizers such as polycarboxylate-ethers (PCE), lignosulfonates and (LS) is reported.

Optimization of Concrete for Prefabrication and Quantification of its Environmental Impact

Stijn Onghena, Steffen Grünewald and Geert de Schutter

An experimental study has been executed to optimize concrete for prefabrication of concrete elements by realizing an early age strength comparable with the reference concrete 100% Ordinary Portland Cement (OPC) and by minimizing the environmental impact. The environmental impact is quantified with two parameters: the emission of CO2 per volume of concrete and an environmental cost indicator, which comprises eleven effects on the environment. The Dutch CUR tool 'Groen Beton 3.2' was used as a source for the calculations with regard to the environmental impact; the background of the environmental cost indicator is elaborated. The study comprises an initial mortar-based study to determine strength levels and environmental impact. At a comparable workability level, specimens were produced of which the compressive and flexural strengths were determined at different ages after casting. For selected

mixtures differences in the heat of hydration were assessed and the mix design was transferred to concrete. The results show that concrete elements can be produced with a much lower impact on the environment and without compromising on the production conditions.

Pavement Management Under Uncertainty: A Heuristic Approach

Omar Swei, Jeremy Gregory and Randolph Kirchain

Pavement management systems have emerged as an effective tool for allocating resources for the maintenance and rehabilitation of pavement networks. This research addresses two key gaps in the existing paradigms by considering a range of sources of variation beyond pavement deterioration and developing a framework that is capable of being granular enough such that material-specific decisions are made across a pavement network. Since the incorporation of both of these aspects will increase the computation cost of a roadway network model, a computationally efficient algorithm is developed using approximate dynamic programming that scales well for managing thousands of pavement segments over a multi-decade time-horizon. The algorithm is subsequently implemented for the management of 3,000 roadway segments in the state of Virginia. Results from the case study indicate that considering variation as it relates to cost has a particularly large impact on the optimal pavement policy and network performance level. Additionally, results indicate that the inclusion of multiple pavement materials when cost uncertainty is considered can lead to improved network performance relative to a network that only considers one pavement material.

Performance of Calcium-Sulphoaluminate Cement for Concrete Pavements Applications: A Numerical and Experimental Investigation

Sergio Tortelli, Adriano Reggia, Giovanni Plizzari and Maurizio Marchi

Curling and cracking of concrete pavements made with Ordinary Portland Cement (OPC) are unavoidable phenomena due to the concrete shrinkage of the material. In particular, the non-uniform distribution of moisture throughout the pavement thickness due to the water evaporation gradient determines a non-uniform distribution of the shrinkage, with larger values near to the surface exposed to drying especially at the early ages. This phenomena induces tensile stresses in the pavement leading to a high risk of cracking, becoming one of the major issues in large concrete pavements in terms of functionality and durability. A performant and sustainable solution is represented by the use of calcium sulphoaluminate cement (CSA), an eco-friendly binder characterized by low-shrinkage and rapid-hardening behavior. The use of a binder made blending OPC and CSA speeds up the construction process, increasing the early age performance and reducing the number of joints with respect to a standard OPC-based concrete floor. This work presents the restrained shrinkage analysis, performed by means of numerical analyses, for the prediction of curling and cracking of a concrete pavement made with an OPC/CSA cement. The analysis procedure was validated through by the comparison with the experimental results obtained from the execution of a field test on a 9.5x1x0.15m concrete slab.

Post-impact Assessment of Reinforced Concrete Plate Load Capacity

Gilberto Nery, Falk Hille and Andreas Rogge

An experimental investigation has been carried out to collect fundamental data and to develop a deeper understanding of the effect of impact damage on the load capacity of concrete plates. The paper presents a series of load tests for reminiscent load capacity of reinforced concrete plates after an impact load. Two types of reinforced concrete plates measuring 1.5 x 1.5 x 0.3 m were subjected to the impact of a flat-nose hard projectile. The two types were casted with the same reinforcement and 80 or 40 MPa concrete. After the impact, the plates were tested for their ultimate load capacity and the results were compared to the undamaged reference plates. The results were also analyzed with some classical empirical damage models and the relation between the residual load capacity and the impact load was observed.

Properties and Performance of Ground Glass Fiber as a Pozzolan in Portland Cement Concrete

Prasad Rangaraju, Hassan Rashidian, Gordon Nameni and Godwin Amekuedi

This paper will present findings from a comprehensive investigation on the potential of ground glass fiber (GGF) for use as a sustainable pozzolan in portland cement concrete. Material properties of GGF were characterized and based on the findings, a series of performance tests were conducted on mortars and concretes containing GGF as a cement replacement material. In this study, specific emphasis was placed on investigating the potential of GGF to cause or promote deleterious ASR when used in concrete or mitigate ASR due to the presence of other reactive sources of silica present in concrete. In this study, GGF was used as a cement replacement material at dosage levels of 0, 10, 20 and 30% by mass replacement of cement. The results from this study showed that the finely ground GGF not only possessed excellent pozzolanic behavior but also had significant ability to mitigate any ASR caused by the presence of reactive aggregates. The use of GGF was not found to cause any self-induced ASR deterioration in concrete. Findings from other rheological, mechanical and durability studies showed superior behavior of mortar and concrete mixtures compared to the control mixtures.

ProScale: A Life-Cycle Approach to Hazard, Risk and Exposure Assessment for the Construction Industry

David Green

In today's world, there is more and more interest in the ingredients that go into the products we purchase. Whether that is food, clothing, personal care items or the structures that we live in. In the building industry, the interest in information about product ingredients has been geared more toward deselection (red lists, black lists) than optimizing ingredients for performance enhancement. Also, it has been very difficult to evaluate the products toxicological performance along its full life cycle as this requires hazard, exposure and risk assessment. ProScale is a new approach for toxicity indicators using REACH data and applicable within life cycle thinking. REACH provides a pool of information on exposures, hazards and risks of chemicals. This presentation will walk the audience through the initial concepts and current work that has been completed on the development of ProScale. Actual examples will be provided to further engage the audience and an opportunity to become involved in the development of the final model will be introduced.

Recent Advances on the Use of Sustainable Structural Concrete: A Materials Perspective

Leandro Sanchez, Martin Noël, Gholamreza Fathifazl and Bruno Damineli

Considering the progressive depletion of sources of high-quality construction materials worldwide, it is essential that engineers are able to build new resilient infrastructure through the use of more eco-efficient/environmentally friendly materials (e.g. lower cement content concrete - LCCC), while optimizing the recycling of materials resulting from industrial processes and demolition of infrastructure having reached their expected service life (e.g. recycled concrete aggregates - RCA). However, the long-term performance of these new materials is still relatively unknown, which delays their implementation in the construction market. This paper discusses the recent advances made in the last ten years with respect to sustainable materials for structural applications, especially through the use of RCA and LCCC. Examples of laboratory and field studies and data will be shown and a critical analysis of the potential use of these materials for structural applications will be performed. Moreover, current research needs and opportunities as well as ongoing research studies at the University of Ottawa will also be discussed and presented.

Recycling of End of Life Concrete to New Concrete

Francesco Di Maio, Somayeh Lotfi, Peter Rem, Han Xia, Maarten Bakker and Mingming Hu

In the Netherlands most of construction and demolition waste (CDW) is currently used as base for roads construction. However in the near future other applications are needed because of the imbalance between demand and offer of such material. At European Union level most of the CDW is still being land-filled. Within a European funded FP7 project (C2CA) it has been developed a 100% end-of-life (EoL) concrete separation process that produces both aggregates of quality equivalent to natural aggregates suitable for use in new concrete production and a Calcium rich (C-S-H) rich feedstock for low-carbon cement production and other special products eliminating problematic residues. Further research is ongoing within a follow up H2020 project (Hiser) to valorize the latter fine fraction. Hence the C2CA technology will contribute to creating a sound material-cycle in which there is a simultaneous pursuit of environmental preservation and economic development in the form of new business opportunities and improved competitiveness of European industries.

Recycling of Sewage Sludge Ash (SSA) as Construction Materials

Zhen Chen and Chi Sun Poon

In Hong Kong, about 1,000 tonnes of sewage sludge is produced every day representing a major fraction of the total solid waste. Traditionally, sewage sludge has been land applied or disposed of at landfills. These disposal methods cause environmental issues like odour problems, leachate causing water pollution, and occupying landfill space. To tackle the disposal problem of sewage sludge, the Hong Kong government has just built and commissioned a 2000 tpd sewage sludge incinerator. Through incineration the volume of waste can be reduced by up to 90%, but the residual ash is still required to be managed properly. Research is being conducted at the Hong Kong Polytechnic University on using SSA as a supplementary cementitious material. Preliminary results showed that increasing the percentage of SSA led to decreasing workability of cement mortars, and ground SSA was beneficial to workability although grinding increased the surface area of SSA. The results also demonstrated that SSA contained many open and isolated pores which could take up substantial amount of water so that the effective water/binder ratio was reduced.

Responsible Sourcing Certification for Concrete

James Bogdan

As stakeholders place pressure on companies to disclose material items beyond financial health, companies are finding themselves reporting in the age of transparency. This trend also has found its way into Green Building standards, specifically the LEED v4 rating system. Complimenting new credits driving product transparency, i.e., environmental and health product declarations, v4 introduced a credit to reward project teams for selecting products verified to have been extracted or sourced in a responsible manner. In response, NRMCA acted with international organizations to develop "The Concrete Responsible Sourcing Scheme. This presentation will discuss the responsible sourcing scheme, its aspects, and participation and audit requirements to become a certified organization.

SEACON – A New Research Project Towards the Sustainability of Concrete

Antonio Nanni

A project titled "Sustainable concrete using seawater, salt-contaminated aggregates, and non-corrosive reinforcement" or SEACON was funded under the aegis of the European research program called Infravation. SEACON's aim is to advance the position of the concrete industry as a whole by making its product more economical, more durable and more environmentally-benign. This is accomplished by addressing the following two challenges: a) resource and energy efficiency in road construction and maintenance (Eco-design); and, b) virgin material reduction by substitution or recycling. SEACON is an attempt to pursue the goals of SUSTAINABILITY by removing unnecessary regulations that prevent a better exploitation of byproducts, recycled materials and, where appropriate, saltwater without affecting the quality and durability of the final product. SEACON outcomes are intended for the concrete industry but also the general public as a demonstration of the commitment of this industry to be a significant player and partner in addressing global challenges associated with preserving quality of life and environment. This paper provides a summary of the technical tasks and expectation of this research program in addition to its preliminary experimental results.

Self-sensing Cementitious Composites with Graphene Nanoplatelets

Radhika Pavgi, Zhangfan Jiang, Andrei Ramniceanu, Osman E. Ozbulut and Devin K. Harris

This paper investigates the self-sensing capabilities of graphene nanoplatelet (GNP) reinforced hydraulic Portland cement composites. In particular, the effects of GNP content on the electrical properties and piezoresistive characteristics of mortar specimens are explored. The GNPs used in this study have an average thickness of 2 nanometers and a diameter between 1-2 microns. Standard prismatic mortar specimens containing different GNP concentrations are prepared. To aid the dispersion of non-functionalized GNPs, a water-reducing admixture along with ultrasonication of the solution is employed. To assess the distribution quality of the GNPs, scanning electron microscope imaging is used, while the effects of this dispersion on resistivity are measured using a four-point probe method. In parallel, the piezoresistive response of GNP-reinforced cement composites is evaluated under a four-point bending test.

Statistical Mixture Design to Optimize Eco-efficient Binder for Infrastructure Construction

Seyedhamed Sadati and Kamal H. Khayat

The study reported in this paper presents an analytical method established to investigate the performance of sustainable binders made with high volume supplementary cementitious materials (SCMs) that can be used for infrastructure construction. Minimum of 50% of the cement weight is replaced with SCMs, including ground granulated blast furnace slag (GGBS), Class C fly ash (FA-C), and Class F fly ash (FA-F) to produce eco-friendly binders. Statistical mixture design approach is employed for the design of the test matrix and analysis of the data. Compressive strength, shrinkage, and durability of binary and ternary systems are determined for optimized binders. Various mathematical models are established with R2 values ranging from 0.70 to 0.99. Models are validated with additional experimental data, and candidate blends are optimized for plain and reinforced rigid pavements using multi criteria optimization approach. Two series of blends are proposed for plain concrete pavement applications: 48% OPC, 29% GGBS, and 23% FA-C as well as a combination of 35% OPC, 27.5% GGBS, and 37.5% FA-F. It is also proposed to employ two optimized binders for reinforced concrete pavements: 48% OPC, 34% GGBS, and 18% FA-C as well as the ternary blend with 32.5% OPC, 35% GGBS, and 32.5% FA-F.

Streamlined Building Life Cycle Assessment

Josh Hester, Reed Miller, Jeremy Gregory and Randy Kirchain

Life Cycle Assessment (LCA) tools are time-consuming, require burdensome data collection, and are poorly integrated with the design process. Additionally, use phase impacts are often left out of LCAs because predicting the energy consumption of a building is itself a complex problem. We present a streamlined building LCA methodology called the Building Attribute to Impact Algorithm (BAIA) that allows the simultaneous calculation of embodied (attributable to materials) and use-phase impacts based on uncertain or low-fidelity definitions of materials and building attributes. BAIA captures the variability in predicted impacts introduced by the low-fidelity building definition. This is accomplished through the underspecification of building attributes, where unknown or uncertain attribute values may be represented by a group of related attribute values. LCAs are then conducted in a Monte Carlo framework where one value is randomly selected for each underspecified attribute. The resulting probabilistic distribution of life cycle impacts quantifies the variability introduced by underspecification, and statistical analysis of these results provides feedback on which attributes contribute the most to the variability in predicted impacts.

Strength Performance and Life Cycle Assessment of Recycled Aggregate Concrete with Class C Fly Ash

Austin Dada

Many municipalities specify the use of recycled aggregate concrete for various means including the construction of highway fill and pavement design. Recycled aggregate concrete, however, has not found great use in the state of Alabama in the United States. The following research performed determines the compressive and flexural strength of recycled aggregate concrete garnered from demolition sites in the Birmingham, Alabama area along with the use of class C fly ash as a substitute for 20% of the cement in the mix. The mix designs studied were a control mix with no fly ash or recycled aggregates, a mix containing 20% class C fly ash substitution for cement, a 25% recycled aggregate and 20% class C fly ash mix, a 50% recycled aggregate and 20% class C fly ash mix, and a 100% recycled aggregate and 20% class C fly ash mix. The 28 day results showed that all of the mixes exceeded the design compressive strength of 4000 psi, except for the 25% recycled aggregate mix. The 50% recycled aggregate mix exhibited the highest 28 day compressive strength of all of the mixes researched. The 56 day compressive strength of the concrete mixes was noticeably greater than the 28 day strength for all of the mixes researched but with a greater volatility (standard deviation) in results for the 50% recycled aggregate and 100% recycled aggregate mixes. A life cycle analysis is then conducted on the use of fly ash as a cement substitute.

Study on the Effect of Expansive Additive on Autogenous Deformation in Early Age

Atsushi Teramoto, Kazuhiro Hotta, Takaaki Ohkubo and Ippei Maruyama

This paper focuses on the mechanics of shrinkage reducing effect with expansion additives in very early age. In order to extract the expansion which is caused by expansion additive from the behavior of autogenous shrinkage of ultra-high strength cement paste with expansion additive, hydration pressure theory was applied. In the hydration pressure theory, the statistical thickness of adsorption is a main factor that determines driving force of shrinkage, therefore, it was considered that the difference of strain between with or without expansion additives in the same statistical thickness of adsorption. The expansion of cement paste which is caused by expansion additives mainly appeared after 1 day. The expansion of this period has a connection with production amount of calcium hydroxide. It indicates that calcium hydroxide which produced from expansion additives contributes to the expansion after 1 day. And it was observed that the time dependent change of produced amount of ettringite was modified by adding shrinkage reducing agents.

Super Absorbing Polymers Increasing the Frost-thaw Resistance of Concrete Roads

Bart Craeye, Gilles De Brabander, Joop Bovend'Eerdt and Geert Cockaert

This research evaluates possible improvement of freeze-thaw durability of concrete by adding super absorbing polymers (SAP) to the fresh mix. SAPs can absorb water as much as 50 times of its own weight. The polymers also have the ability to gradually release the absorbed water to the concrete during the hardening and hydration processes due to self-desiccation, providing internal curing of the concrete. Another effect of the SAP is the creation of small cavities in the concrete due to the donation of absorbed water to the hydration process that can serve as expansion vessels to counteract the expansion of frozen (expanding) water inside saturated concrete during freezing, thus increasing the frost-thaw resistance. The effect of the polymer on the scaling and degradation due to frost-thaw cycles is investigated. Compressive strength tests, weight loss measurements, microscopic inspections on thin sections and scanning electron microscopy are performed. Secondly, the effect of different amounts, different mean sizes and different types of SAP added to the fresh mix is studied and evaluated: one commercially available and one prototype polymer are used throughout the investigation. Finally, the frost-thaw testing are executed according to the standard ISO/DIS-4846-2 and CEN/TS 12390-9, who are also compared in this project.

Sustainability and Durability of Concrete Placed in Cold Weather

Nash Hasan

This paper presents guidelines for successful concrete production, placement, protection and curing during cold weather conditions, when the ambient air temperatures remain below 32 ◦F (0 ◦C).The cold weather guidelines are based on the results of the US Army Engineer Research Center, Cold Regions Research and Engineering Laboratory (CRREL) large scale tests on formulations of antifreeze concrete with specialty admixtures, conforming to ASTM Type C. The specialty admixtures lower the freezing point of fresh concrete to an internal temperature of 23 ◦F, and allow early strength gain, without external heat source. The guidelines discuss mixture proportions, setting times and compressive strength results for concrete, at placing and curing at ambient temperatures of 20 ◦F. Recommendations for field testing, simulating the actual subfreezing conditions, and guidelines for quality control during production of concrete, and protection requirements of concrete during curing are included. Relative concrete production costs for cold weather concreting are also provided.

Sustainability of Rubberized Concrete as Highway Pavement Construction Material

Rui Liu

At the end of 2009, about 113.6 million scrap tires were stockpiled in the United States. This research examines the sustainability of recycled tire chips (1/4 in-1 1/2 in) as coarse aggregate in concrete mixtures for highway pavement. Fresh and hardened concrete properties (e.g. air content, compressive strength, permeability, and resistance to freeze-thaw cycling) were tested for mixtures with 100%, 50%, 30%, 20%, and 10% (volume) of coarse aggregate replaced by tire chips. The mixture with 10% coarse aggregate replaced by tire chips had the best performance. The air content reached 6%. Workability was comparable to the control mixture. At 28 days of age, the compressive strength exceeded 4200 psi. In addition, the mixture had moderate permeability and high freeze-thaw durability factor. A regional life cycle assessment model considering the impacts of scrap tire stockpiles is utilized to evaluate the economic and environmental sustainability of rubberized concrete mixture with 10% tire chips. Although the direct economic benefit is low, the indirect environmental cost saving indicates a promise of developing rubberized concrete as highway pavement construction material.

Tensile Behaviour of Distinct Hooked End Steel Fibre Shape and Geometry on Material Properties of Self-compacting Concrete

A O Okeh, David W Begg, Stephanie J Barnett, Nikos Nanos

A laboratory investigation was carried out using different steel fibre hooked-end shape and geometry at 0.25%, 0.5%, 0.75% and 1% fibre content in self-compacting concrete to obtain material properties. Four point bending test and uniaxial direct tension test were used as the test methods. The obtained results show that alterations in the hooked end shape and geometry from single hook shape to multiple hook shape affects the pull-out response in terms of peak pull-out load and dissipated energy. There is an increase in flexural strength, ultimate flexural strength and fracture energy up to a maximum of 1.7, 2.1 and 11 times respectively when compared to plain concrete. However, the post-cracking response of steel fibre reinforced self-compacting concrete is not only influenced by the alteration of hooked end shape and geometry but also the percentage content of steel fibre and type of stress application.

The Characterıstıcs Of Boron Modıfıed Actıve Belıte (BAB) Cement And Its Utılızatıon In Concrete Technology

Aydin Saglik

The production of boron modified active belite (BAB) cement reduces the emission of CO2 by up to 25% and saves a significant amount of energy due to low clinkering temperatures around 1325°C. In this paper, by using boron modified active belite (BAB) and normal Portland cement, produced in Goltas Cement Factory, some chemical, physical and mechanical tests were carried out to investigate characteristics of the cement and concrete phases and evaluate the results in this first part of the research. In the second part of the research, the microstructure of concrete made with BAB cement will be investigated. BAB cement was standardized by Turkish Standard Institution as a type of Portland cement called “boron modified active belite cement." It has been found out that BAB cement has very low heat of hydration and less than 52.5 Cal/g at 7 days. Moreover, its early strength at first 7 days is less than that of normal Portland cement, however, beyond 7 days it gives same levels of strength values up to 28 days and later ages displays higher strength values than normal Portland cement. In the durability part of tests like water permeability and chloride penetration resistance tests, concrete specimens made with BAB cement indicated more resistance as comparing to the specimens made with normal Portland cement even at lower cement contents.

The Durability of Concrete Produced Using CO2 as an Accelerating Admixture

Sean Monkman, Mark MacDonald and Doug Hooton

A comprehensive durability evaluation of carbon dioxide treated concrete was conducted. The effect of the carbon dioxide in the fresh state was assessed in terms of slump, air content, plastic density, heat of hydration and set time. Hardened state tests included compressive strength, flexural strength, bulk resistivity, water absorption, freeze-thaw durability (ASTM C666), drying shrinkage (ASTM C157), chloride permeability (via ASTM C1202, bulk resistivity, and bulk diffusion testing), and deicer salt scaling. Comparisons were made between a reference concrete batch, a batch that contained a conventional accelerating admixture, and a batch subjected to the carbon dioxide addition.The concrete exposed to the optimum dose of carbon dioxide was found to reduce the time to initial set by 40% and time to the final set by 33%. The carbonated concrete had a compressive strength that was 14% higher than that of the control at one day and 10% higher at 3 days. Later compressive strengths were equivalent to the control. The concrete durability was essentially unaffected by addition of the CO2. The acceleration due to the carbon dioxide was not as pronounced as that provided by the conventional accelerator but the early strength was increased.

The Effects of Cellulose Ether Admixture on Fresh Cement Pastes Submitted to a Hydraulic Gradient

Alexandre Pierre, Arnaud Perrot and Vincent Picandet

In this study, an oedometric cell has been adapted to investigate the influence of cellulose ether (CE) dosage on the permeability of fresh cement pastes. Rheological shear flow measurements have been carried out to evaluate the viscosities of the initial interstitial liquid and the percolated fluid that has filtrated

through the fresh cement paste. Comparison of both viscosities allows the evaluation of the amount of CE adsorbed by the cement particles over a wide range of CE dosage. Comparison of an apparent viscosity computed from permeability measurements and viscosity computed from rheological measurements shows that CE strongly modifies the particle networks above the overlap concentration. The results of this study suggest that CE aggregates are formed and plug part of the cement pastes porosity. As a result, the apparent viscosity increases and leads to a strong decrease in the material's apparent permeability. Finally, apparent permeabilities are reported for CE dosages ranging from 0% to 0.5%. The results of the study show that combination of rheological and permeability measurements offers a promising method to analyze how CE acts on fresh cement pastes, that are subjected to a hydraulic gradient induced by casting processes.

The Effects of Zeolite as Supplementary Cement Material on Pervious Concrete

Alireza Joshaghani

Zeolites have been used in portland cement concrete for a decade and researchers tried to investigate enhance performance by increasing replacement amounts this supplementary material. The main purpose of this study is to evaluate suitability of zeolite replacement as a supplementary cementing material in pervious concrete. Zeolite was used at 15%, 25%, and 35% weight percentages as a cement replacement. The results are compared to reference mixtures of fully Portland cement. The variables were zeolite content, aggregate size, and water to cement ratio. Sixteen mix designs were tested to study physical and mechanical properties of hardened concrete including porosity, permeability, compressive strength, tensile strength, and flexural strength at various ages. Results indicate that mechanical properties of the pervious concrete marginally decreased at early age, when compared to the reference mixtures. However, by passing time, the differences were reduced.

The Influence of Pore Size and Freezing Rate on Ice Formation in Concrete

H. S. Esmaeeli, Y. Farnam, D. P. Bentz, P. D. Zavattieri and J. Weiss

Fluid penetration is a primary factor that can influence the freezing behavior of the concrete pavements in cold regions, thereby increasing the deterioration. A one-dimensional finite difference model is developed to describe how the rate of climate change and the broad range of pore sizes may alter the macroscopic freezing behavior of mortar saturated to water. This phenomenological model predicts the temperature and heat flow for mortar samples including the phase transformations associated with freezing of water in the pores. Undercooling phenomenon is also considered during ice formation in this model. The obtained results from a low-temperature longitudinal guarded comparative calorimeter (LGCC) test were compared with numerical results which show a promising agreement. It is observed that ice formation in the water-filled pores larger than gel pores (major fraction of pores that can freeze) can simulate the freezing behavior of the mortar specimen. The rate of ice formation (freezing rate) is significantly increased as the cooling rate decreased.

The New Industry Average Slag Cement EPD Provides a Basis for Assessing Effect of Slag Cement on the Environmental Impact of Concrete Mixtures and Structures

Jamie Meil and John Melander

Released in May 2015, the industry average Environmental Produce Declaration (EPD), for slag cement in North America is the first North American industry average EPD for a cementitious material used in general concrete construction applications. The new standardized format conveniently documents the comprehensive cradle-to-gate Life Cycle Assessment (LCA) information that is the basis for the EPD for product specifiers. Since slag cement is a recovered material that puts to beneficial use what might otherwise be wasted, the use of slag cement to replace a portion of the portland cement in concrete mixtures provides a significant reduction in the environmental footprint of concrete and concrete structures. This EPD simplifies the assessment and documentation of that reduction in environmental impact. The presentation will summarize the industry average slag cement EPD development process and illustrate how EPD information can be used to assess the environmental impact of concrete mixtures and structures. Ultimately this effort will benefit the construction project owner, specifier, ready mixed concrete community, and public at large.

Theory and Reality: EDPs and Low Carbon Concrete in Construction

David Walsh

This presentation examines Sellen Construction's journey from modeling reductions of embodied emissions to the realities of placing low carbon concrete. Informed by several current and recent projects in the Puget Sound region, the presentation will discusses the environmental, owner, aesthetic and economic drivers to reducing cement and concrete's embodied impacts; the process of creating new mix designs and environmental product declarations (EPDs); and the challenges and successes of early adoption. The presentation shares real-world experiences of working with a transit agency to forecast potential embodied emissions savings by implementing new mixes across a transit system, as well as working with public and private owners to place lower cement concrete in high-rise and office projects. The discussion concludes with both the promises and challenges facing general contractors, concrete suppliers, design teams and project owners.

Using Eco-Friendly Cementitious Materials for Sustainable Concrete

Fadel AbuShaaban

Green architecture or urban environment-friendly cities reduces the negative impact of buildings on the environment. Most Dubai buildings are made of reinforced concrete, of which the most important component is the portland cement, which is not an eco-friendly material. In order to participate in converting Dubai to a green city, it is essential to use green cement. This presentation will introduce the Dubai Municipality's directive to all stakeholders of the construction sector to use eco-friendly and sustainable concrete materials in building construction, which will reduce carbon emission and create a more environment-friendly urban environment.

What's Your Biodiversity KPI?

Margaret O'Gorman

Wildlife Habitat Council (WHC) engages with corporations – in the concrete industry and beyond – their employees, and community members to recognize and encourage wildlife habitat projects for conservation, education and recreation. Presenters will discuss on-the-ground conservation programs compatible with concrete operations that enhance biodiversity and promote corporate goals, including those related to social responsibility, sustainability, employee engagement, community relations and STEM education. Attendees will benefit from the panel's experience in aligning their voluntary sustainability standards with contemporary conservation priorities and actions, and how they use data and results allow for evaluation of impact.