Concrete Sustainability Forum VI

by Koji Sakai and Julie K. Buffenbarger

The ACI Concrete Sustainability Forum VI took place in Phoenix, AZ, on October 19, 2013, in conjunction with the ACI Fall 2013 Convention. Preceding forums were held in St. Louis, MO, in 2008[1]; New Orleans, LA, in 2009[2]; Pittsburgh, PA, in 2010[3]; Cincinnati, OH, in 2011[4]; and Toronto, ON, Canada, in 2012[5], in which there were very interesting discussions:

- While deterministic-based methods dictate today's landscape, probabilistic- and risk-based methods need to be introduced;
- A critical piece in ensuring resilient infrastructure is to educate the owners on the importance of durable structures;
- Carbon emissions are growing exponentially, yet there has been no resultant change to building codes in large, developing countries;
- We need to see, quantitatively, what happens economically, environmentally, and socially if we change the safety factor; and,
- There is no significance in saving a few weeks on the construction schedule of a building which is designed to last 100 years.

It is obvious that all these discussions stem from the lack of adequate sustainable technologies and systems. Therefore, the concrete industry must be encouraged to develop innovative technologies and reliable systems.

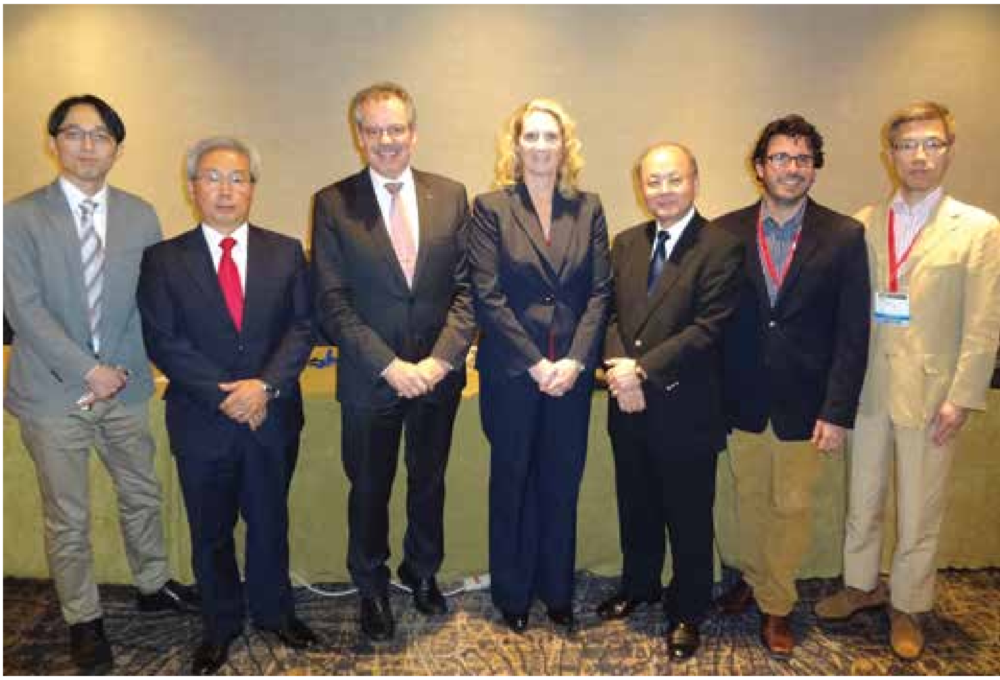
Forum VI comprised two parts:

- Part 1 featured presentations on low- and negative-carbon concrete, sustainable cement, sustainable concrete structures, standards, Product Category Rules (PCRs) and Environmental Product Declarations (EPDs), and sustainability standardization in Korea; and
- Part 2 was a panel discussion in which the speakers interacted with onsite and online participants.

Part 1

Low-carbon, high-performance concrete

Koji Sakai, Professor at Kagawa University, Takamatsu, Japan, presented a new approach for the development of low-carbon, high-performance concrete. There are several methodologies for low-carbon concrete including: efficient raw material use and alternative raw materials and fuel use in cement



Moderators and speakers for the ACI Concrete Sustainability Forum VI, October 19, 2013. From left: Takayuki Higuchi, Dong-Uk Choi, Harald S. Müller, Julie K. Buffenbarger, Koji Sakai, Laurent Barcelo, and Takafumi Noguchi

manufacture, use of supplementary cementitious materials (SCMs) to replace portland cement, reductions of portland cement by using high-range water-reducing admixtures in concrete mixtures, and the use of high-performance concretes. The most efficient method for the drastic reduction of CO_2, however, is the replacement of portland cement with large amount of SCMs. In Japan, 80% CO_2 reduction in portland cement was obtained using blast furnace slag in the construction of the tower foundation for the Akashi Kaikyo Bridge, Kobe and Awaji-shima, Japan, which is the world's longest suspension bridge. However, many cracks with widths of 0.05 to 0.5 mm (0.002 to 0.02 in.) in 3 to 5 m (10 to 16 ft) intervals occurred due to large autogenous shrinkage, low crack resistance, and slow early-strength development.

The cracks were repaired, but to prevent recurrence of this issue, the combination of portland cement replacement with fly ash and slag cement was evaluated. It was found that portland cement replacement with 20% fly ash and 20% slag cement was the most effective concrete mixture combination. The developed concrete mixture showed excellent performance including 45% reduction in CO_2 emissions, increased long-term strength, adequate early strength development, high resistance to cracking, and excellent durability. This low-carbon, high-performance concrete was used for a slab-wall structure.

Negative-carbon concrete

Takayuki Higuchi, Group Leader at Cement and Special Cement Additives Research Laboratory, Denki Kagau Kogyo Kabushiki Kaisha (DENKA), Tokyo, Japan, introduced a negative-carbon concrete, which was the result of the collaboration between the Chugoku Electric Power Co., Inc., and KAJIMA Corporation. CO_2-SUICOM® (Storage Under Infrastructure by Concrete Materials) was developed in which coal ash and a special additive, γ-C_2S, were used and cured in the exhaust gas from a coal power station. The reaction model between γ-C_2S (γ-$2CaO{\cdot}SiO_2$) and CO_2 is:

$$\gamma\text{-}2CaO{\cdot}SiO_2 + 2CO_2 \rightarrow 2CaCO_3 + SiO_2\,(\text{gel})$$

where γ-C_2S is made from $Ca(OH)_2$ and SiO_2 in a rotary kiln.

The CO_2 emission of γ-C_2S is one-fourth that of portland cement. The γ-C_2S can theoretically absorb 400~500 kg (880 to 1100 lb) of CO_2. The carbonation increases the volume of γ-C_2S to 1.75 times. It contributes to the decrease of pore volume in concrete and therefore the increase of concrete strength.

CO_2 contents fixed in concrete by curing with a chamber, in which the CO_2 concentration of exhaust gas was 15~20%, were measured. It was found that the CO_2 emissions from materials were 90.6 kg/m^3 (5.7 lb/ft^3) and the CO_2 fixation by curing in the exhaust gas chambers was 104.5 kg/m^3 (6.5 lb/ft^3). This means that the total amount of CO_2 is below zero.

This negative-carbon concrete was applied for paving blocks. The compressive strength, drying shrinkage, and efflorescence were tested. The results were satisfactory. This concrete is now commercially available.

Sustainable cement manufacturing

Laurent Barcelo, Manager of Strategic Projects for Lafarge Canada, Pointe-Claire, QC, Canada, described the importance of CO_2 reduction from the cement industry and outlined the International Energy Agency (IEA)-World Business Council for Sustainable Development (WBCSD) cement technology roadmap.[6] There are three traditional levers to reduce CO_2: energy efficiency in manufacture, use of alternative fuels (including biomass), and clinker substitution (either via cement or directly in the concrete mixture).

The best available technology in cement manufacturing uses a five-stage preheater with precalciner process enhancing the energy efficiency by 58% over the older wet process. In Germany, more than 37% of fuel is alternative fuel and biomass has been used successfully in cement manufacture. However, there is a large disparity regionally, and the ability to use alternative fuels and biomass provides significant opportunity for global improvement. Barcelo explained that clinker substitution by SCMs is a powerful tool in reducing the CO_2 footprint of concrete. The roadmap anticipates that 56% of the total reduction in CO_2 emissions will come from carbon capture and sequestration (CCS) technologies. These technologies are far from mature and anticipated costs for implementation are high.

To avoid unrealistic CCS costs, we must look for a clinker that leverages all the current advantages, including locally abundant and economic raw materials, high levels of easy reactivity to complement SCMs, increased durability for steel protection, and a much lower CaO content to significantly reduce CO_2 emissions. Of course, this clinker should be suitable for production in existing plants. The BCSAF (Belite-calcium Sulfoaluminate-ferrite) clinker, developed by Lafarge (Aether™) and others, may be one option. The Aether clinker realized a 30% CO_2 reduction in comparison with ordinary portland cement clinker (PCC). However, some challenges regarding cost and properties exist. The Lafarge pilot production runs have shown that material can be produced using existing manufacturing equipment. Durability studies are ongoing.

Sustainable concrete structures with service life design and eco-efficient concrete

Harald S. Müller, Professor at Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany, discussed approaches for increasing sustainability. Sustainability is realized by maximizing service life and minimizing environmental impacts. In order to increase the service life of a structure, adequate service life design (SLD), monitoring and structural inspection, and adequate rehabilitation work are necessary. It is also important to retain the structure's aesthetic design. Regarding the enhancement of performance, the use of building materials with increased strength and durability and materials with additional functionality are required. It is also important to improve resilience. To enhance the performance of a structure, ultra-high-performance concrete (UHPC) is one option.

Necessary measures to minimize the environmental impacts of structures should be considered: use of raw materials with reduced eco-impacts, development of concretes with reduced binder and/or cement clinker contents, and the development of environmentally friendly production and building techniques.

The steps for SLD of structural systems are: 1) system analysis including description of the system, failure analysis, and fault tree analysis; 2) failure probability analysis; and 3) risk analysis.

ISO environmental standardization for concrete sector

Takafumi Noguchi, Professor at The University of Tokyo, Tokyo, Japan, explained ISO standardization on environmental issues for the concrete sector. The standards have been developed by ISO/TC71/SC8 (Environmental Management for Concrete and Concrete Structures), chaired by Koji Sakai, which comprises 13 participating and 11 observing countries. The sections of ISO 13315 developed and under development in the series are:

- Part 1—General principles (ISO 13315-1, published in 2012);
- Part 2—System boundary and inventory data (ISO 13315-2, FDIS stage);
- Part 3—Constituents and concrete production (under preparation);
- Part 4—Environmental design of concrete structures (NWIP);
- Part 5—Execution of concrete structures (under preparation);
- Part 6—Use of concrete structures;
- Part 7—End-of-life phase including recycling of concrete structures (under preparation); and
- Part 8—Labels and declaration (NWIP).

(Note: FDIS is Final Draft International Standard and NWIP is New Work Item Proposal.)

The concrete sector has been using the ISO 14000 series. However, this series was developed for industrial goods and services and its application to the concrete sector's activities, which have inherent differences, is difficult. Therefore, the ISO 13315 standard series has been created to provide common rules in evaluating the environmental impacts of concrete and concrete structures.

PCRs and EPDs

Julie K. Buffenbarger, Construction Specialist for Lafarge, Medina, OH, reviewed the market growth of sustainable construction and the development of EPDs which will become the new standardized measurement for environmental impacts of materials and services.

The sustainable construction market is projected to reach $145 billion in 2015. Much of its growth has come from the wide adoption of sustainable rating tools for buildings such as the Leadership in Energy and Environmental Design (LEED) rating system by the U.S. Green Building Council (USGBC). Most recently, initiatives such as Architecture 2030 ask for dramatic reduction in global fossil fuel consumption and greenhouse gas (GHG) emissions of the built environment by altering the way cities, communities, infrastructure, and buildings are planned, designed, and constructed. The ultimate goal is the design of carbon-neutral buildings by 2030.

To achieve net-zero energy buildings, unbiased, scientific-based tools must be used to accurately quantify environmental impacts of building materials. EPDs provide the quantitative embodied impacts of the products. EPDs are supplied by manufacturers of products and services. The path to create an EPD includes: 1) establishing a PCR for data collection via ISO 14024; 2) conducting an LCA of manufacturing; 3) verifying the LCA; 4) preparing an EPD draft; 5) validating the EPD; and 6) registering the EPD.

The question remains how easily this will be accomplished for concrete, as there are thousands of mixture designs and variability with materials procurement. Today, industry associations such as the Portland Cement Association (PCA) and the National Ready Mixed Concrete Association (NRMCA) are carrying much of the burden by creating industry "average" EPDs for cement and concrete, which may be used in LEED v4 and other rating systems requesting EPDs.

Buffenbarger also mentioned that the advent of building information modeling (BIM) enables environmental impact information to be readily integrated into the design process, allowing designers the ability to evaluate total building impact performance early in the design stage.

Sustainability standardization in Korea

Dong-Uk Choi, Professor at Hankyong National University, Ansung, South Korea, discussed the development of environmental standards for concrete in Korea. Korea was the 7th highest GHG-emitting country globally in 2011. Under "GHG and Energy Target Management," 480 business enterprises that emit more than 60% of GHGs in Korea are under direct control by the government for GHG emission and energy consumption.

Two main players at the industry level, the Korea Cement Industrial Association (KCIA) and the Architectural Institute of Korea (AIK), are creating standards to meet the new GHG and energy targets. New cement standards will permit use of up to 10% SCMs (5% at present). Other strategies include electric power generation using heat recirculation, alternative raw materials and fuels for cement kilns, use of more energy efficient equipment, and introduction of portland limestone powder cement.

The new 2013 AIK Building Construction Standard Specification requires constructors to submit an "Environmental Management Plan for Construction" including: 1) increasing the reuse/recycling amount of construction and demolition wastes and industrial by-products; 2) environmental management on construction sites; 3) reduction of GHG emissions; 4) reduction of natural resources; and 5) water resource management. The former two are mandatory and the latter three are optional.

The Korean Concrete Institute (KCI) and Korean Institute of Construction Technology (KICT) have completed drafting the following standards:

- Type III declaration on cement;
- Type III declaration on aggregates; and
- Type III declaration on ready-mixed concrete.

Type III declarations provide consumers with the information on quantified life-cycle environmental performance of a product.

Part 2

Acting as Panel Moderator, Sakai presented the following discussion points:

- Is the industry going in the correct direction for the development of innovative low-carbon cement/concrete?
- What are the keys to accelerating SLD for a sustainable concrete structure?
- What are the essential benefits to introducing EPDs in the concrete industry?
- What are the opinions of the industry on the development of an international environmental or sustainability standard for the concrete sector?
- Is the concrete sector taking proper action for sustainable development?
- What are the barriers to introducing new sustainable and resilient concretes in practice?

Due to time limitations, a full discussion could not take place. However, it was concluded that:

- Many actions toward steadily increasing concrete sustainability have been taken in the last 5 years;
- Continuation of the development of new sustainable technologies and systems is imperative; and
- Practical sustainable construction applications should be promoted.

We hope that the readers of this article consider the preceding questions and take action as members of the concrete industry for creating a sustainable society.

Summary

Nearly 100 onsite registrants participated in the ACI Concrete Sustainability Forum VI, and 49 additional attendees participated through the webinar.

It is the authors' opinion that the ACI Concrete Sustainability Forum has played an important role in providing ideas and exposure to the development and adoption of innovative technologies, sustainable practices, and standards for the concrete industry over the last 6 years. The seventh Sustainability Forum is being planned for Washington, DC, in the fall of 2014. As sustainability becomes more widespread and adopted, the usefulness of future Forums will be considered and evaluated in 2015.

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Selected for reader interest by the editors.

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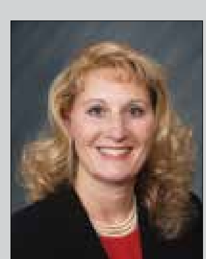

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