A case for low-lime cement

The cement and concrete industry is re-inventing itself through new and efficient processes to not only reverse its environmental impact, but to make improvements to the whole supply chain of the building materials industry. This sustainability drive has seen the emergence of low-clinker cements, including cements that have a reduced lime content.

■ *by* ***Dr Vahit Atakan, Dr Sada Sahu and Dr Nick DeCristofaro,*** *Solidia Technologies, USA*

Recognising the need to lower its carbon and energy footprints, the cement industry actively pursues four practices that can help reduce the industry's carbon footprint:

- improvement of energy efficiency in cement production
- alternative fuel use
- clinker substitution
- carbon capture and storage.

As part of a strategic approach to meet its CO_2 reduction goals and conserve energy and natural resources, the industry has also adapted clinker substitution technologies. In addition to transforming a waste product into a usable commodity, low-clinker cements can help save energy, reduce pollutants and lower the consumption of raw materials.

The production of low-lime clinkers such as Solidia® clinker helps to reduce CO_2 emissions from cement production

Reducing lime content

Solidia Technologies® has developed patented processes that offer cement and concrete manufacturers an alternative means of achieving the targeted energy conservation and pollutant reduction goals. Solidia Cement™ is produced using a low-lime containing raw mix, and thus produces low-lime containing calcium silicate phases. These phases produce a cement that is non-hydraulic, consumes less energy and emits less greenhouse gas. Thus, Solidia Cement is also more sustainable than ordinary Portland cement (OPC).

Solidia Concrete™ is made with Solidia Cement and cures with CO_2 instead of water. A typical concrete product consumes about 240kg of CO_2/t of cement. In addition to helping meet CO_2 reduction goals, Solidia Concrete performs better, is more durable and cost-effective than traditional concretes, and typically cures in one day. When compared to the 28 days required for traditional concrete to reach full strength, this time saving translates into costs savings for manufacturers.

Inspired directly by the CO_2 challenge, Solidia's processes allow the industry to address its environmental challenges with solutions that offer solid value to manufacturers and immeasurable value to the planet. That said, bringing a new technology to an industry that has not changed in nearly 200 years is a daunting prospect.

Pavers ready for curing: Solidia Concrete® cures with CO_2 rather than water and typically cures in one day

A low-lime cement

To meet CO_2 reduction goals the cement industry strives continuously to substitute clinker with various supplementary cementitious materials (SCMs), such as fly ash, slag, silica fume, natural pozzolanic materials and fillers such as limestone. Even with all the clinker substitution efforts, the World Business Council for Sustainable Development (WBCSD) predicts the CO_2 reduction achieved by producing low-clinker cements will reach only 10 per cent of the industry's 2050 CO_2 reduction target. Solidia Technologies' new low-lime cement offers an alternative approach to help the industry towards its goal at a much faster pace.

Adoption of these approaches has been

made simple. Solidia's patented cement chemistry and curing processes offer the building materials and construction industries the ability to manufacture cement and concrete products within existing plants and using traditional design specifications, with minimal requirements for new supply chains and capital investment. Solidia Cement is composed of a family of "green," low-lime calcium silicate phases that are similar, but not identical to, the chemistry of Portland cement. As a result, it can be produced in existing cement kilns with the same raw materials that are used to make OPC, although in different proportions.

Solidia Cement is produced using less limestone and at lower temperatures than are necessary for Portland cement. These factors translate into a reduction in CO_2 emissions during cement manufacturing, from 940kg/t for OPC to 660kg/t of Solidia Cement (~30 per cent reduction). Other pollutants associated with cement production, such as mercury, are also reduced by approximately 30 per cent.

For concretes made with Solidia Cement, curing is achieved by a reaction between the low-lime calcium silicate compounds $CaSiO_3$ and $Ca_3Si_2O_7$ and gaseous CO_2 within a moist environment. Unlike its OPC-based counterparts, CO_2-cured Solidia Concrete does not react with water. On average, 70-80 per cent of the water used in the Solidia Concrete formulation can be recovered during the CO_2-curing process. The remaining water is retained in the concrete and can be recovered if needed.

Deriving its strength from the formation of $CaCO_3$ (calcite) and SiO_2 (silica gel), the curing reaction of Solidia Concrete is written as:

$$CaSiO_3\,(s) + CO_2\,(g) \xrightarrow{H_2O} CaCO_3\,(s) + SiO_2\,(s) \quad \text{[Eq 1]}$$

$$Ca_3Si_2O_7\,(s) + 3CO_2\,(g) \xrightarrow{H_2O} CaCO_3\,(s) + 2SiO_2\,(s) \quad \text{[Eq 2]}$$

The carbonation curing reaction is exothermic and releases -87kJ/mole of heat. The heat generated during the reaction is dissipated by the evaporation of water. The curing process is controlled by counter diffusion of CO_2 and H_2O molecules.

The curing process described above enables Solidia Concrete products to permanently sequester 200-300kg of CO_2/t of Solidia Cement used in the concrete formulation. Depending on the specific ratios of fine and coarse aggregate and Solidia Cement used in the concrete mix, the final Solidia Concrete part may contain between about 3-7 weight per cent of sequestered CO_2.

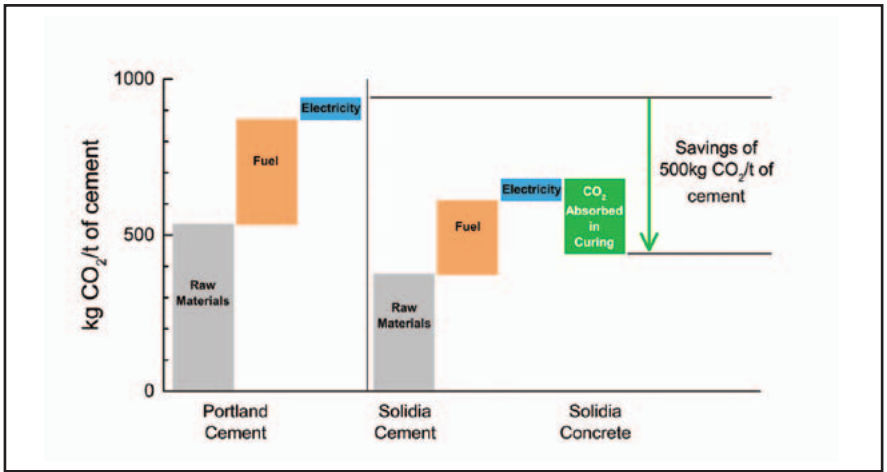

Figure 1: comparative CO_2 emission from raw material fuel and electricity for Portland cement (~940kg/t) and Solidia Cement (680kg/t). The curing reaction in Solidia Cement consumes CO_2 (~240kg/t) resulting in up to 500kg/t reduction in CO_2 emission

Production in existing kilns

Working with global building material leader LafargeHolcim as a commercial partner, Solidia has demonstrated that common cement kilns and raw materials can be used to produce Solidia Cement simply by:

- adjusting the relative amounts of the raw materials that are fed into the kiln
- operating the kiln at a lower reaction temperatures.

While this approach does not completely avoid the decomposition of limestone and the high temperature reaction of CaO and SiO_2 associated with the manufacture of OPC, it reduces the amount of limestone decomposed and energy consumed by 30 per cent. This reduces the amount of CO_2 emitted from a cement plant by ~260kg/t of cement produced.

When coupled with ~240kg of CO_2 captured during curing, the production and use of 1t of Solidia Cement will reduce airborne CO_2 by up to 500kg when compared to the production and use of 1t of Portland cement (See Figure 1). This CO_2 saving is equivalent to a clinker factor of between 0.47-0.53 in an OPC-based system.

Solidia Cement can potentially replace all Portland cement currently in use as it can be made everywhere that Portland cement is made. In the North American market alone, airborne CO_2 could theoretically be reduced by 5.0 x 10^7t/year (10^8t of OPC x 0.50t of CO_2).

Where sustainability adds value

The inclusion of all the SCMs, namely fly ash, bottom ash and slag, led to improvements in the workability of Solidia Cement mortars, especially when class F fly ash was used, suggesting a reduction in the overall water demand in the mixtures thereby allowing for more rapid curing. Solidia Cement can be partially replaced with slag, class F and class C fly ash. The SCMs in Solidia Concrete do not produce any pozzolanic reaction but are rather just fine fillers.

Tests have shown that the incorporation of SCMs can further reduce the carbon footprint associated with the production and use of Solidia Cement. The research demonstrated that waste materials such as fly ash and ground granulated blast furnace slag can be used to replace Solidia Cement by as much as 40 per cent by weight in concrete formulations. When the ability to replace Solidia Cement with moderate amounts of fly ash or blast furnace slag are considered, the total CO_2 savings associated with Solidia Cement production and use can be further reduced, resulting in an additional reduction in clinker factor. Moreover, some of the SCMs, such as slag, can partially carbonate during concrete curing, realising further savings in CO_2.

As the carbon economy comes online, the demand for alternative cementitious materials grows among concrete manufacturers. Solidia's new, alternative process presents the industry with a sustainable and potentially profitable means of meeting that demand. ■