THE ROAD TO LOW CARBON CONCRETE

Unabated urbanisation continues, and growing cities are made largely of concrete – a strong and durable material made from varying proportions of Portland cement. **One tonne of cement produced releases an estimated 0.87t of carbon dioxide** (global average), and globally, the cement industry accounts for 8% of total greenhouse gas emissions, which is incompatible with global climate change commitments. It is an industry in need of lowering its footprint, and there are a number of ways this can happen:

Until now, the focus has been on ensuring energy efficiency in factory processes and using alternative fuels to substitute conventional fuels.

Going forward, the emphasis will be on geopolymers and alternative materials that can be used instead of cement, without compromising the strength and durability that concrete is known for. Pulverised fuel ash (PFA) – also known as fly ash – is an example of an alternative material. Fly ash is a by-product of Eskom's coal-burning power generation process, and Sasol's coal-to-liquid fuel process, so is abundantly available in South Africa. There is an opportunity to put this waste material to beneficial use but the problem is ensuring a source of consistent quality to get the science of concrete mixing right every time.

Beyond 2050, a lot of faith is being put in carbon capture and storage (CCS, see *earthworks* issue 34) as a way to reduce emissions in the sector.

HOW TO MAKE CEMENT

Ingredients: limestone of high purity, clays and shales

STEP 1 Combine ingredients in a cement kiln at about 1400°C to form a **flux**, which results in a crystalline material known as **clinker**. The actual chemical reaction to transform limestone into reactive Portland cement releases 0.54kg of carbon dioxide per 1kg of clinker product. Therefore, the less clinker used, the less associated emissions.

STEP 2 Cool clinker rapidly to set the crystal in the highest reactivity form possible.

STEP 3 Grind into fine powder and mix with ground gypsum to form a calcium-enriched mixture (CEM). (CEM 1 = 95% clinker; CEM 2 = 65%-94% clinker; CEM 3 [marketed as eco-cement] = 20%-64% clinker)

In South Africa, year-on-year emissions in the cement industry have reduced thanks to use of clinker substitutes i.e. PFA, ground granulated blast-furnace slag, or limestone. Clinker substitution has increased from 12% in 1990 to 41% in 2009. Use of waste tyres in cement kilns also reduces the percentage of CO_2/GJ of energy consumed by 11%.

GEOPOLYMER CEMENT

This is heralded globally as an emerging solution to reduce the carbon intensity of cement. Geopolymers replace ingredients in the making of clinker with different inorganic binders. It provides the same functions as Portland cement but with a different underlying chemistry. Currently most commercially available geopolymer cements are based on two materials: fly ash and ground granulated blast-furnace slag, but it can be made with almost any material with a high enough content of aluminosilicate. In tests, geopolymer cement has shown greater acid resistance when compared to Portland cement, thus a low-hanging fruit option would be to increase use of geopolymer cement in corrosive environments, such as wastewater treatment plants. On the contrary, a drawback of geopolymer cement is that it can take longer to set, although this would not be a problem in precast concrete operations.

HOWEVER, THE UPTAKE OF GEOPOLYMERS IN SOUTH AFRICA HAS BEEN SLOW

What's holding us back? Partly professional risk aversion. There is an absence of national standards covering the use of geopolymers, and consulting engineers are reluctant to sign off on projects using materials that do not meet national standards because of the high risk involved if the material fails.

However, this does not mean there is no more that can be done in South Africa. The opportunity for substitution of ingredients to make concrete, rather than cement/clinker, are where gains can be made. Here, cement replacement is becoming more common.

HOW TO MAKE TRADITIONAL CONCRETE

Ingredients
60-75% aggregates (course and fine)
14-20% water
7-15% cement
Up to 8% air

HOW TO MAKE HYBRID CONCRETE

Ingredients
50–75% aggregates
14–20% water
0.5–2% cement
Up to 25% waste/by-product (pulverised fuel ash, ground granulated blast-furnace slag, or limestone)
Up to 2% air

HOW TO MAKE ALKALI-ACTIVATED CONCRETE

Ingredients
40–55% aggregates
Up to 15% water
Up to 25% waste/by-product (pulverised fuel ash, ground granulated blast-furnace slag, or limestone.)
Up to 20% commercial activator, (combination of alkalis – sodium silicate and sodium hydroxide)
Up to 2% air

Step 1: In a large mixer, combine all ingredients. Different proportioning allows for different strengths and durability.
Step 2: When concrete has been mixed and ingredients activated, pour into desired mould for shaping.
Step 3: Leave to dry and cure.

55% About 55% of emissions from cement-making are from transforming limestone (via heating) to lime + CO_2

32% About 32% of cement-related emissions are from burning fossil fuels to reach the high temperature required

13% About 13% of emissions relate to electricity used to grind and transport material

The GBCSA's Green Star SA rating system awards points for the replacement of cement within projects, but it is argued these percentages could be increased. A number of industry professionals agree every building should be doing at least 25% cement replacement as a minimum. There are even local examples of this target being impressively exceeded.

One example is Cape Town's Portside skyscraper, constructed in 2011. Here, thanks to the willingness of the project team to experiment with finding more environmentally sustainable solutions that did not compromise safety, the majority of the concrete had 65% of the Portland cement replaced with a slag by-product from the steel industry known as GGCS (ground granulated Corex slag). Further development work was conducted to make a concrete with 85% cement replacement. Some 5 646 762kg of CO_2 was saved thanks to cement replacement on this project.

Another local example is the Transnet City Deep Container Terminal in Johannesburg. Here, alkali-activated concrete was used, thus 64% cement was replaced.

In 2015, the Loeriesfontein wind farm constructed the bases of its wind turbines using up to 95% Portland cement replacement mixture.

With the growing trend toward net-zero buildings and the impending carbon tax for South African industries, the cement industry will need to continue investigating alternative production fundamentals. **"We can't continue our use of limestone for cement any more than we can keep burning coal,"** emphasises Beyond Zero Emissions.

SOURCEBOOK

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Worldwide Fund for Nature (WWF), presentation and workshop "Constructing a case for geopolymer cement", July 2017.
Rethinking Cement: Zero Carbon Industry Plan, by Zero Carbon Australia's Beyond Zero Emissions series
A calculator to estimate the carbon footprint of a given concrete mix is available from the Concrete Institute at: www.theconcreteinstitute.org.za/concrete-model