

Building Materials for a sustainable future – cement

By Joe Mapiravana

Introduction

Concrete is second only to water in terms of the most consumed substances on earth. Cement is the “glue” which holds concrete together and it is therefore a construction material which is produced and consumed in huge quantities worldwide. Global cement production is about 2.8 billion tonnes per year (WBCSD, 2011a) and growing at an annual rate of close to 4%, largely driven by demand from developing countries.

The South African cement industry produces about 17.5 million tonnes of cement per annum. This is about 0.6% of current annual global production and constitutes about 16.5% (CIDB, 2007) of the market share of the major South African construction materials. The relative contributions of the traditional materials to building cost in South Africa follow the order:

1. cement and reinforced concrete (35%), of which 50% is cement
2. plain carbon steel products (structural steel, tiles, flat and profiled sheets, door frames, window frames and garage doors) (23%)
3. bricks and blocks (12%)
4. Timber and wood (10%)
5. Tiles and sanitary ware (9%)
6. plastics (4%)
7. non-ferrous metals (4%)
8. glass (3%)

Four companies account for more than 80% of cement produced in South Africa. These are AfriSam South Africa (Pty) Ltd, Natal Portland Cement (NPC) Cimpor, Lafarge South Africa and Pretoria Portland Cement (PPC). Sephaku Cement is the new kid on the block.

Environmental challenges

The use of cement based building and construction materials offers several socio-economic benefits. Cement-based building materials provide the strength, safety and durability of buildings and other building infrastructure - contributing to the quality of life. The thermal mass of cement-based building materials significantly contributes to the energy efficiency of buildings by reducing heating and cooling loads over the buildings' entire life cycles.

However, the environmental impacts associated with the production of cement are a cause for concern since:

- The cement industry is responsible for at least 5% of global carbon dioxide emissions (WBCSD, 2011a)
- Cement kilns produce airborne emissions of sulphur dioxide, nitrous oxide, mercury, dioxins and furans and particulate matter (ground Work, 2006).
- Cement production is energy-intensive and accounts for 2% of global primary energy consumption; and 5% of global industrial energy consumption (Worrel, 2001).
- The use of “alternative fuels” in the cement industry protects non-renewable stocks of fossil fuels and reduces carbon dioxide emissions. However, the use of alternative fuels may increase the concentrations of heavy metal toxins such as lead, cadmium and chromium in cement kiln dust (ground Work, 2006).

Cement sustainability Initiative

The World Business Council on Sustainable Development (WBCSD) started a sector project targeting cement sustainability – the Cement Sustainability Initiative (CSI). It is a global effort by 23 major cement producers with cement plants in more than 100 countries worldwide who believe there is a strong business case to pursue sustainable development. The CSI's objective is to have in excess of 100 cement plants around the globe collectively improve the environmental performance of the global cement industry. The participants have all signed the CSI Charter which captures the individual member actions included in the Agenda for Action which was published in 2002 (WBCSD, 2011b). The Charter is a living document that reflects developing sustainability issues in the cement industry. The CSI's Agenda for Action is a five-year work program to steer cement companies towards practical actions, focusing on the following six main work packages (WBCSD, 2011c):

- CO₂ and climate protection
- Responsible use of fuels and raw materials
- Employee health and safety
- Emissions monitoring and reduction
- Local impacts on land and communities and
- Concrete Recycling

CSI member companies joined the initiative at various times. All member companies have signed a Charter to, implement, at least, these work packages as part of their contribution to sustainable development. On joining, companies have four years to meet the requirements of the CSI Charter. The CSI secretariat manages the process and ensures that companies are aware of and fulfil their various commitments. The Charter was updated in 2009 and is renewed as necessary to address emerging issues. Since the Charter was issued in 2002, CSI members have additionally agreed to conduct third party assurance audits of a number of the key performance indicators (KPIs), which are publicly reported. Since 2006, companies carried out KPI assurance audits of their CO₂ data every two years, at least. They have also committed to independent KPI assurance audits of their safety data, beginning 2008. Other KPIs will be added over time.

Green initiatives by the Cement and Concrete Institute

The Concrete Institute embarked on various initiatives to improve the sustainability of cement and concrete industries.

Cement industry Initiatives

- CO₂ emissions study
- Energy source substitution (tyres)
- Use of extenders
- Reduction of point source emissions using bag house filters; and electrostatic precipitation
- Pre-calciner and pre-heater use in cement production process
- Rehabilitation of mines

Concrete industry Initiatives

- Use of admixtures together with extenders to minimise resource use (water and cement). This approach also increases the durability
- Substitution of in-situ with pre-cast elements to minimise resource use through volume reduction
- Permeable elements, namely, pavements, can be used to stop “ponding” and at the same time collect and re-use rainwater

- Concrete structures are known to sequester carbon dioxide from the atmosphere. A Danish study has found that 50% of the volume of concrete will be 'carbonated' over 70 years of any building's service life. This sponge effect makes concrete a more green choice than previously thought, emphasising how global sustainability can be achieved with concrete.
- Overall benefits of concrete – thermal mass, durability, recyclability and low maintenance. Note Roman structures built of concrete still standing today
- Thermal mass contributes to energy efficiency of buildings by reducing heating and cooling loads
- Waste minimisation – the incorporation of blast furnace slag, fly ash and silica fume help to re-use waste materials

Codes and Standards Initiatives

- Use and sales of extended concrete is very high
- The durability has also been increased to meet the needs of major clients, in particular, SANRAL andESKOM

Table 1: Cement and mortar research objectives, recent developments and their impact on sustainability

RESEARCH OBJECTIVES	RECENT DEVELOPMENTS	IMPACT ON SUSTAINABILITY
<ul style="list-style-type: none"> • Partial or total cement replacement. Lifecycle cost reduction, life cycle assessment and durability. Characterisation of waste and metakaolin replaced/extended cement. • Innovative cements development. New/alternative cement such as carbon negative magnesium-based cement that absorbs 0.6ton CO₂ per ton cement on hardening. Patent pending. • Recycling/re-use of industrial waste and by-products in cement. Development of blended cement using industrial wastes 	<ul style="list-style-type: none"> • Blended cements with various degrees of cement extension/replacement by fly ash(up to 70%), ground granulated blast furnace slag, rice husk ash, maize cob ash (20-50% is used to bond maize cob fibre cement roofing sheets),nano structured zanolite, nano clay cement binder (montmorillonite), zeolite, incinerator ash, phosphogypsum, paper sludge waste, pulverised fuel ash(bottom ash), diatomite, metakaolin, stronger macro-defect free glycerol plasticised PVA-calcium aluminate (secar 71) and calcium aluminate phenol resin cements. • Alternative lower carbon footprint carbon negative magnesium silicate based cement produced using less heat energy. Magnesia cements. Geopolymer cements. • Recycling of cementitious industrial waste in cement replacement • Blended cements with various degrees of cement extension/replacement by fly ash(up to 70%), ground granulated blast furnace slag, rice husk ash, maize cob ash (20-50% is used to bond maize cob fibre cement roofing sheets),nano 	<ul style="list-style-type: none"> • Reduction of the content of virgin cement clinker – saving cement resources and reducing carbon footprint, embodied energy and production cost of cement • Reduction of carbon footprint and extension of raw materials base for cement manufacturing • Extension of the life of cement resources and reduction of carbon footprint, embodied energy and production cost of the cement • Reduction of the specific energy consumption of

<ul style="list-style-type: none"> • Light-weighting • Modification/improvement of cement properties (sulphate resistance, acid resistance) by admixtures such as silica fume, GGBFS, nano-silica, zeolites and plasticizers. • Performance evaluation of different kinds of cements including: high strength 	<p>structured zanolite, nano clay cement binder (montmorillonite), zeolite, incinerator ash, phosphogypsum, paper sludge waste, pulverised fuel ash(bottom ash), diatomite, metakaolin, stronger macro-defect free glycerol plasticised PVA-calcium aluminate (secar 71) and calcium aluminate phenol resin cements.</p> <ul style="list-style-type: none"> • Foamed cement products • Prefabricated structural nano clay cement bonded zanolite toughened insulation panels. Use of various clinker grinding aids(water, aliphatic amines (e.g. triisopropanolamine), phenols and phenol derivatives and inorganic electrolytes at 50-500ppm levels) and cement admixtures to improve clinker fluidity and grindability by reducing agglomeration and cement properties such as setting speed decrease or increase (alkali/quick lime activation), sulphate resistance, acidic resistance (by silica fume, nano silica), strength(by 0.5% polycarboxylate ether superplasticizer) • Cements with improved properties containing proprietary admixtures & superplasticizers • A wide range of cements have been 	<p>cement grinding and hence reduction of embodied energy, carbon footprint and production cost</p> <ul style="list-style-type: none"> • Reduction of embodied energy component of transportation, carbon footprint and cost • embodied energy and carbon footprint • Waste recycling and reuse – saving resources • Performance enhancement permits
---	--	--

<p>cement (HSC 60-90MPa)high performance cement (HPC 90-150MPa), ultra high performance cement(UHPC</p> <ul style="list-style-type: none"> • Geopolymers • De-polluting, self-cleaning and photo-catalytic properties. 	<p>developed with wide range of strength (70-350MPa) for different applications including HSC, HPC, UHPC</p> <ul style="list-style-type: none"> • Total cement replacement by alternative greener geopolymeric binders • TiO₂ containing de-polluting and self-cleaning cements are coming on stream 	<p>use of thinner and lighter structural members – reducing raw material and energy usage,</p> <ul style="list-style-type: none"> • Enhancement of product durability (e.g. sewer pipes) and lowering carbon footprint • Reduction of corrosive species from the atmosphere and improvement of air quality and people's health and safety
--	--	---

CARBON FOOTPRINT - OPC CONTENT RELATIONSHIPS

Figure 1 shows CO₂ emissions as a function of the OPC content for the geopolymer cement E-crete™. E-Crete™ is a special geopolymer blend of fly ash and slag which is activated to form a geopolymer concrete [1]. E-Crete™ is currently the only commercialised Geopolymer intended to be used as an alternative to Portland cement, and it is currently used in Australia. The figure suggests that the reduction of OPC content of binders is associated with a reduction in the carbon footprint of the binders – thus increasing the environmental sustainability of the cement binders. This can be done by the incorporation of waste materials such as ground granulated blast furnace slag and fly ash in cement. In particular the manufacture of the geopolymer “E-Crete™” liberates substantially lower amounts of carbon dioxide per tonne of cement produced.

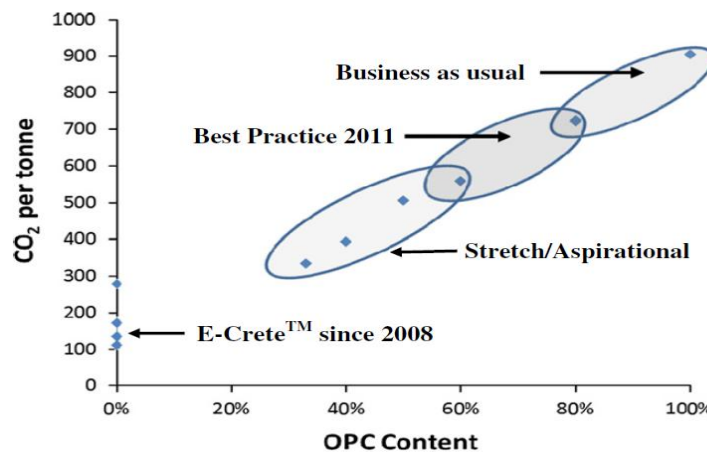


Figure 1: CO₂ emissions as a function of OPC content [1]

Screening Life Cycle Assessment study of Ordinary Portland cement and a Fly Ash/Slag geo-polymer

Background

This is a screening LCA study carried to scope the carbon footprint of Ordinary Portland Cement (OPC, CEM 1, at least 91% clinker content by weight) as compared to geopolymer concrete (a geopolymer cement made up of 85% blast furnace slag/fly ash; and 15% sodium hydroxide/sodium silicate or potassium hydroxide by weight).

The analysis tool is SimaPro 7.3. The study relies on LCI datasets of European and American origin which is shipped standard with SimaPro. The results are therefore not necessarily representative of South African conditions since energy mix (hydro-, thermal, nuclear etc.) is different.

The study considers the production stage only (cradle-to-gate analysis). The use, maintenance and end-of-life disposal aspects, including transportation in between were not considered in this analysis

Assumptions

1. European conditions
2. Cradle-to-gate comparison only
3. As a waste material the carbon footprint of blast furnace slag is zero

Five scenarios with 1kg geopolymer with varying activator type and/or content were compared against a fixed 1kg OPC/CEM I (91% clinker), at plant, using Eco-invent data version 2.1 unit process. Results of the simulation are shown in Table 2.

Table 2. Comparison of carbon footprints of simulated geopolymers against 1kg OPC/CEM I (91% clinker)

Geopolymer	1	2	3	4	5
[(OPC/CEMI)/Geopolymer] carbon footprint ratio	4	5	5	3	1.5

Geopolymer Key

- 1kg Geopolymer cement (0.85kg blast furnace slag, 0.15kg sodium silicate, BUWAL 250 database)
- 1kg Geopolymer cement (0.85kg blast furnace slag, 0.15kg sodium silicate, furnace liquor, 37% in H₂O, , Eco-invent data version 2.1 unit process
- 1kg Geopolymer Cement (0.85kg blast furnace slag, 0.075kg sodium silicate, furnace liquor, 37% in H₂O, at plant; and 0.075kg sodium hydroxide, 50% in H₂O, production mix, all Eco-invent data version 2.1 unit processes.
- 1kg Geopolymer sement (0.85kg blast furnace slag, 0.15kg potassium hydroxide, all Eco-invent data version 2.1 unit processes).
- 1kg Geopolymer cement (0.85kg blast furnace slag, 0.15kg sodium silicate, furnace liquor, 37% in H₂O, at plant, all Eco-invent data version 2.1 unit processes

NB. The magnitude of simulated geopolymer carbon footprints relative to 100% OPC in Table 2 are of the same order of magnitude as those in Fig.1. 100% OPC has carbon footprint that is 5 to 6 time that of E-crete, for example. This gives confidence in the applicability of the simulated data.

Conclusion

Various initiatives and ongoing research and development have been started to enhance the sustainability of cement. Chief among these is the use of extenders to reduce the carbon footprint of cement to enhance its environmental sustainability; reduce natural resource usage, environmental degradation and pollution. It appears that the future trend will be towards the development of zero OPC binders to achieve the lowest binder carbon footprints. Arguably, the carbonation of cement over time and its relatively high thermal mass (as concrete) may still make it an attractive building material choice for a sustainable future.

References

1. <http://www.cnci.org.za/EN/Content.aspx/Pages/Sustainability/Concrete-Benefits>
2. http://www.acmp.co.za/who_is_acmp.htm
3. AfriSam, 2011. <http://www.afrisam.co.za/about.asp>
4. Cimpor, 2011. <http://www.cimpor.pt/Default.aspx?cntx=rAAsDm9XZ1jhh4aCn4z4K4l3wltLF5lZbw%2FLjNTBIEQ%3D>
5. C&CI, 2011. About Us. <http://www.cnci.org.za/EN/Content.aspx/Home>
6. GroundWork , 2006. Analysis and write up of burning alternative fuels in cement kilns.
7. InEnergy, 2010. *Cement and Concrete Institute concrete industry greenhouse gas emissions.* <http://www.cnci.org.za/EN/Content.aspx/Pages/Sustainability>
8. Lafarge, 2011. <http://www.lafarge.co.za/wps/portal/LSA/LafargeCement#Our%20Investment%20In%20South%20Africa>
9. PPC, 2011. http://www.ppc.co.za/pages/about_profile.cfm
10. WBCSD, 2011a. Sector projects – cement <http://www.wbcd.org/templates/TemplateWBCSD5/layout.asp?typ>
11. WBCSD, 2011b. CSI Charter http://www.wbcdcement.org/index.php?option=com_content&task=view&id=38&Itemid=93

12. WBCSD, 2011c. CSI – Agenda for Action.
http://www.wbcscement.org/index.php?option=com_content&task=view&id=37&Itemid=92
13. [1] J.S.J. van Deventer, J.L. Provis, P. Duxson, “Technical and commercial progress in the adoption of geopolymer cement,” in Minerals Engineering, Elsevier 2011.
14. J. Mapiravana, PG Report: “Building Materials Research and Development Priorities”, Technical Report Number : CSIR/BE/CON/IR/2007/006/B March 2009
15. M.N. Dlamini and J. Mapiravana, “Fly ash and GGBS Geopolymer Concretes – A Review” , in CSIR Consolidated PG Report 2011/2012
16. Worrel, E., Price, L, Martin, N., Hendriks, C, Ozawa Meida, L. 2001. Carbon dioxide emissions from the global cement industry.
17. *Energy and the Environment*, 26:303-329