The objective of the paper is to provide an understanding of the South African concrete industry's environmental burden in terms of natural resource consumption and carbon dioxide equivalent emissions (CO2-e).

Keywords: environmental burden, CO2-e emissions, concrete industry, leadership of the CoMSIRU (Concrete Materials & Structures) from the University of the Witwatersrand, Johannesburg. His teaching and research interests lie in environmental engineering and eco-design with a focus on structural integrity.

INTRODUCTION

Background

In the mid-20th century and beginning of the 21st century, the increased uptake of concrete as a structural material has led to sustainability issues. The worldwide consumption of concrete has been estimated to be increasing gradually at 6.4 billion m³ in 1997 (Alcimin 2010) to 8 billion m³ in 2009 (CEMBUREAU 2011). This amount will continue to increase, particularly in the developing countries, due to an exponential increase in population growth, urbanisation and economic growth. However, while concrete production contributes to socio-economic development, evidence suggests that this growth is associated with an escalating negative and irreversible impact on the environment.

The main purpose of this paper is to provide an understanding of the South African concrete industry's environmental impact in terms of natural resource consumption and CO2-e emissions. The review covers current practices in the concrete construction field in South Africa (SA) and their implications for the environment. Elaboration in terms of detail and quantification is given for the environmental burden generated during the manufacture of raw materials for concrete and their transportation to site. Four-year average (2005–2008) data is provided for resources consumed and wastes emitted during the quarrying and manufacture of raw materials for concrete.

South African concrete industry

The concrete industry in South Africa comprises cement manufacturers, aggregate producers, admixture suppliers, cement extenders (fly ash and slag) suppliers, ready-mix and precast concrete producers, concrete product manufacturers (including producers of cement building blocks, fibre cement roof sheets, concrete pipes and concrete roofing tiles), designers of structural concrete (civil and structural engineers), building and civil engineering contractors, and small-scale cement and concrete product consumers (e.g. home builders). The activities of the South African concrete industry have been formalised in the recent past as part of government and private industry investment in new (and replacement) construction of 2010 FIFA World cup stadiums and other infrastructure projects, e.g. the Gautrain Rapid Rail Link, airports, and so on. Further consumption of large quantities of energy and resources for concrete production is expected in the foreseeable future to meet the demands of the rapidly expanding population.

This paper investigates the resource flows and carbon dioxide equivalent (CO2-e) emissions generated from the manufacturing activities of concrete construction materials in SA for the period 2005 to 2008. The resource flows are the raw material use (tonnes), and the CO2-e emissions are anthropogenic CO2 emissions and other greenhouse gases (GHG) such as NOx and SO2.

Life-cycle of concrete

Modern concrete is composed of a mixture of aggregates (60%–80%) and cement (5%–12%) and water (14%–21%), and usually includes other constituents such as mineral components (cement extenders/additives) and chemical admixtures (e.g. air-entraining agents, water reducers and accelerators), and occasionally fibres (<1%) (Van Oss & Padovani 2002). Concrete is used in the construction of pre-stressed, reinforced and un-reinforced concrete structures. The life-cycle of concrete covers all activities spanning from the extraction and processing of raw recycled materials to the final decommissioning and demolition of the structure for waste/reuse/reuse of its materials. The scope of studying the life-cycle phases of concrete can be classified into three, as shown in Figure 1. The first phase is the cradle-to-gate phase and comprises all relevant processes from raw materials extraction (cradle), manufacturing and processing of the materials and their transportation to the processing plant, within the plant and the batching plant and/or construction site. Life-cycle phases cover the concrete mixing, construction of the structure, on-site transportation activities, operational phase, demolition of the structure and disposal of demolished material to a landfill. The final phase, grave-to-cradle, refers to end-of-life material recovery strategies that include the recycling and reuse of the demolished material and waste.

This study gives a comprehensive review of the cradle-to-gate environmental impacts of concrete in SA. In summary, the scope of this study includes:

1. Investigating and quantifying raw materials directly consumed in the extraction and manufacture of materials for concrete production. The review omits the environmental impacts arising from the production of mining machinery and processing of secondary materials such as gypsum.
2. Identifying and quantifying the corresponding CO2-e emissions generated directly in the extraction, manufacture and transportation of the materials.

ENVIRONMENTAL IMPACTS OF CONCRETE CONSTITUENT MATERIALS

Cement

Portland cement production involves the chemical transformation of raw materials: calcium oxides (63%–69% by mass in cement), silica (19%–24%), alumina (4%–7%) and iron oxide (1%–6%) into various types of cementitious products, by-products and wastes. The Portland cement manufacturing process consists of five main steps:

1. Quarrying of limestone and transportation of raw materials to the processing plant.
2. Preparation of “raw meal” for pyro- processing, whereby, all raw materials (crushed limestone, iron ore, clay or shale) are mixed together in the correct proportions (raw meal homogenisation) and finely ground.
3. Pyro-processing of raw materials to produce Portland cement clinker using the wet or dry process. The latter refers to the process whereby raw materials are first ground and heated before being fed into the kilns, whereas in the wet process, the raw materials are crushed, ground and mixed as slurry. The most efficient dry-process kilns use approximately 2.9 GJ per tonne of clinker (http://www.energyefficiencyia.org/docs/industrysectorscement_production_draftMay05.pdf). Wet-process kilns are more energy intensive and can consume more than twice the amount used by dry-process kilns (Gartner 2004). All cement kilns in SA use the dry process.
4. Final grinding of the clinker together with inter-grinding with a small proportion of gypsum to produce Portland cement. Waste products from, for example, powder storage (fly ash), iron oxide manufacturers (blast furnace slag) and others can be used as partial replacements for Portland cement to form blended cement, either by inter-grinding with the clinker, or separate grinding followed by inter-blending.
5. Transportation of the finished product to the consumer in bulk or in bags. Typical transportation distances of the cement to site can vary. This review assumes...
Carbon equivalent emissions for cement are due to: (1) calcination or decomposition of limestone (CaCO₃) to calcium oxide (CaO), in the process liberating CO₂; and (2) road burning in pre-processing. Secondary sources of CO₂ emissions arise from the combustion of fossil fuel required to produce the electricity consumed by cement manufacturing operations and from the transport of raw materials and the finished product to consumers (Association of Commissi oned Material Producers (ACMP), 2011).

Carbon equivalent emissions for cement decreases in SA are made by a cement industry characterised by four major producers (as of 2009). Other producers are expected to enter the industry in the coming years. The term ‘cementitious products’ refers to cements complying with SANS 50197-1 (which corresponds to equivalent EN 197 specifications) and cement extenders sold directly to end users such as ready-mix concrete producers. When considering the four-year average (2005–2008), approximately 20.4 Mt of raw materials per year were used in the production of cementitious materials. On average, 12.8 Mt of binders were produced per year. The binders produced included Portland cement and blended cements such as CEM IIA, CEM III, CEM IV and CEM V, all produced in accordance with SANS 50197-1. Figure 2 gives the tonnage for each binder produced. Of the total 12.8 Mt of binders produced per year on average between 2005 and 2008, approximately 37% (4.73Mt) went towards the direct production of concrete. This figure constitutes 17% ready-mix production, 36% concrete product manufacturers and 4% directly for civil construction works, as shown in Figure 3. The percentage value for concrete production could well be higher than 37% as it does not account for the 55% of cement sales to independent blenders (4%) and cement re-sellers (49%). In addition, a part of the 5% cement sold directly to building construction represents that used in the production of concrete buildings, and another part in mortar-based applications (masonry mortar, plastering and a base/sub-base for flooring). However, to avoid greater inaccuracies in analysis, this review assumes that 37% of all cementitious materials produced in SA went towards concrete production in the years 2005–2008.

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Carbon-equivalent emissions from aggregates

There is no readily available local energy consumption data and emissions data that indicates the impact of the production of natural quartz fine aggregates from that of coarse aggregates. Extracting and processing a tonne of both dry and coarse aggregates requires an average of 8.1 kg of CO₂-e (InEnergy Report 2010) as shown in Table 2. Table 3 gives the total amount of CO₂-e emissions generated in the production of aggregates for concrete for 2005 to 2008, based on the ASPASA data given in Figure 4. The amount of fine and coarse aggregates used in concrete production has steadily increased over the four-year period (2005–2008). An average of 32.1 Mt of aggregates used in concrete production led to the production of 2.0 x 10⁶ t of sand and 260 x 10⁶ kg CO₂-e emissions. **Table 3 Environmental impacts of aggregates for concrete during the period 2005–2008**

<table>
<thead>
<tr>
<th>Year</th>
<th>Tonnes of aggregate</th>
<th>Total kg CO₂-e emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>28.4 x 10⁶</td>
<td>230 x 10⁶</td>
</tr>
<tr>
<td>2006</td>
<td>31.9 x 10⁶</td>
<td>258 x 10⁶</td>
</tr>
<tr>
<td>2007</td>
<td>33.9 x 10⁶</td>
<td>275 x 10⁶</td>
</tr>
<tr>
<td>2008</td>
<td>34.1 x 10⁶</td>
<td>276 x 10⁶</td>
</tr>
<tr>
<td>Average</td>
<td>32.2 x 10⁶</td>
<td>270 x 10⁶</td>
</tr>
</tbody>
</table>

**SANS (South African National Standards)**

SANS 10010-1: The Structural Use of Concrete. Part 1: Portoria: SABS.

SANS 10010-2: The Structural Use of Concrete. Part 2: Portoria: SABS.

SANS 10010-3: The Structural Use of Concrete. Part 3: Portoria: SABS.

SANS 50197-1, SAN 50413-1 and SANS 1491: Construction Demolition Waste Conference. Pretoria: C&CI (Cement and Concrete Institute South Africa)

Optimising kiln processes and plant efficiency of cement kilns: CEM III/CEM IV/CEM V, whereas the demand for CEM I is reduced. This has a positive impact on the reduction of the CO₂-e emissions of the concrete industry in South Africa.

**CONCLUSION**

The purpose of this study was to evaluate the use of recycled and electrical energy efficiency of cement kilns. Optimising kiln processes and plant efficiency during cement production results in the reduction of CO₂ emissions and also brings down the cost of production. All the cement kilns in SA use the dry processing of raw materials, which is more energy efficient compared to the wet process. It is important to continue to monitor and improve cement kiln processes to reduce the amount of energy and resources used to create cement.

**REFERENCES**

Alcott, P. C., 2011. Cements of yesterday and today: The history of Portland cement and private industry investment in new cement plants, or blast furnace slag from iron and steel works, or fly ash from coal combustion plants. Blended cements produced to comply with provisions of SANS 5097-1, SANS 1491 parts 1, and 3. The use of blended cements reduces the amount of cement that is needed to be produced, lowers the CO₂-e emissions of the concrete industry. These amounts are expected to increase in the future due to government and private industry investment in new cement plants or blast furnace slag from iron and steel works.

The rapid rate of urbanisation and population growth in South Africa means the use of alternative materials, such as carbon taxes, there are a number of techniques to reduce the CO₂ emissions and energy use of the cement industry. While conserving primary aggregates, and reduces pressure on existing landfill disposal. This is evidenced by the significant difference in data on the production of aggregates as reported by both ASPASA and the DAMI. Cement is the main contributor of CO₂ emissions, contributing on average 94.7% of the total emissions by the concrete industry. The use of blended cements reduces the amount of cement that is needed to be produced, lowers the CO₂-e emissions of the concrete industry.

The Structural Use of Concrete. Portoria: SABS.

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