**Dominik Oetiker**

Sika Technology AG, Zürich, Switzerland

# Polycarboxylate ether polymers and their influence on sustainability in concrete production

## 1. Introduction

The concrete industry accounts roughly for more than 5% of mankind's carbon dioxide emissions. With climate change mitigation and adaptation measures increasing, concrete demand is expected to grow even further. In developing countries in particular, concrete production is forecast to grow as modernisation and growth continues. It is therefore crucial to identify technologies to reduce the carbon dioxide and environmental footprint of concrete production.

### *1.1. Levers to improve the environmental footprint of concrete*

The cement roadmap prepared by WBCSD and the International Energy Agency outlines a possible transition path for the industry to make continued contributions towards a halving of global carbon dioxide emissions by 2050. It estimates that the industry could reduce its direct emissions 18% from current levels by 2050. The four distinct carbon-reduction levers that are identified in the report are:

- Thermal and Electrical efficiency in production processes.
- Alternative fuel use for making clinker.
- Clinker substitution by supplementary or complementary cementing materials.
- Carbon capture and storage (CCS).

By enlarging the perspective from cement to the complete production process of concrete, one can identify more opportunities. Modern superplasticising/high-range water-reducing admixtures for instance allow for the reduction of water and cement at the same time while maintaining, or even reducing the water/cement ratio (w/c ratio) (2). For a given cement content, the w/c ratio is well correlated with permeability, strength and durability of the concrete and consequently is used as a proxy for concrete quality. A lower w/c ratio means lower permeability and higher strength and durability of the concrete. The optimization of concrete mix design with admixtures offers therefore an additional opportunity to further improve the environmental footprint of concrete.

### *1.2. Life cycle assessment*

The main purpose of life cycle assessment (LCA) is to improve the environmental impacts of products and activities by guiding the decision-making process. LCA is one of the most comprehensive methods to assess the environmental impacts of a product or activity over its entire life cycle. LCA aims at providing comprehensiveness in two respects: Firstly by taking into account all relevant life cycle aspects of a product or activity (extraction of raw materials, manufacturing, transport and distribution, use, end of life treatment), and secondly by analysing different environmental impact categories. This helps to avoid optimizing a system by merely shifting environmental burdens between different environmental impact categories or from one product stage to another one.

## 2. Case studies

### *2.1. Optimisation of concrete mix design with PCE based admixtures*

Admixtures are added to the concrete mix to control specific characteristics such as curing time and behaviour, frost-thaw resistance, workability, strength and durability. PCE polymer based admixtures are widely used as superplasticising/high-range water-reducing admixtures.

**Characteristics & Mechanism:** The comb-shaped PCE polymer consists of a polycarboxylic acid backbone (polycarboxylate) and polyether side chains (Figure 1). The negatively charged backbone permits adsorption on the positively charged cement grains. The dispersion of the cement particles works by steric stabilisation. This lowers the friction between the particles and reduces the amount of water to achieve a given viscosity of the concrete mix. The mechanism can be used in different ways to influence the properties of a concrete mix:

- to reduce water content for increased strength and reduced permeability/improved durability
- as a cement dispersant at the same water content to increase workability
- to optimize concrete mix design regarding a desired w/c ratio

**LCA of concrete mix design**: A life cycle assessment of two concrete mixes produced in the laboratory has been calculated. The composition and properties of the mixes are shown in Table 1. Concrete mix II contains a PCE polymer based admixture. Concrete mix I is a concrete without admixture dosage. The functional unit

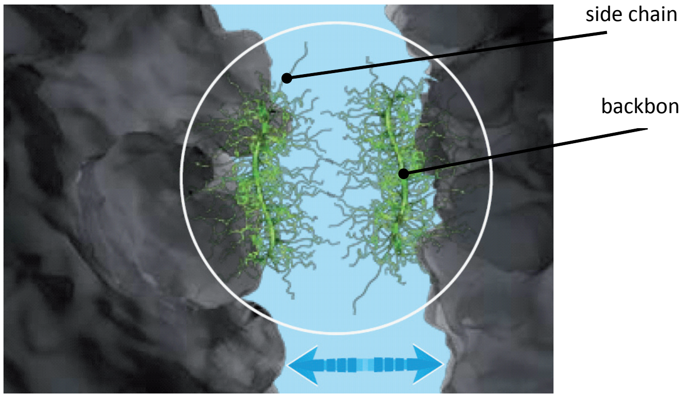

Fig. 1. Illustration of steric stabilisation of cement grains with PCE based admixtures

of the LCA is one cubic metre of concrete.

In a first step, the concrete mixes have been modelled in the software GaBi. The datasets for the modelling were retrieved from commercial databases (European Reference Life Cycle Database, PE International and ecoinvent). In a second step, an impact assessment on the inventory data has been calculated following the CML characterisation scheme 2001. In addition to that, the Eco-indicator 99 value has been calculated (Table 2). This method offers a way to measure various environmental impacts, and shows the final result in a single score (4). In the calculation of concrete mix II, all raw materials, production processes and packaging of the admixture have been taken into account. All other assumptions are equally valid for both mixes.

The use of a PCE polymer based admixture in mix II allows for the reduction of the cement content in the mix design. This reduction leads to an overall better environmental performance for every impact category. The relative improvement differs between the impact categories and ranges from 11% to 19%. The environmental impact of the admixture in mix II is more than offset by the reduction in cement content. In addition to that, the strength of concrete mix II could be improved compared to mix I.

Table 1

COMPOSITION AND PROPERTIES OF CONCRETE MIXES USED FOR THE LCA

| Batch size | 1/35 m$^3$ | **Mix I** | **Mix II** |
|---|---|---|---|
| Cement-type | | CEM I 42.5 | CEM I 42.5 |
| Cement content | kg/m$^3$ | 350 | 280 |
| Admixture Dosage (CEM) | % | 0.0% | 1.2% |
| Aggregates total 0/32 mm | kg/m$^3$ | 1’820 | 2’005 |
| Gravel/Sand | kg/m$^3$ | 1’092 / 728 | 1’203 / 802 |
| w/c-value | | 0.52 | 0.48 |
| Water | l/m$^3$ | 182.0 | 134.4 |
| Fresh concrete temperature | °C | 26.7 | 25.3 |
| Flow table spread - 5’ | cm | 44 | 42 |
| Fresh concrete density - 10’ | kg/m$^3$ | 2395 | 2418 |
| Air content - 10’ | % | 1.5% | 2.0% |
| Compressive strength 7d | N/mm$^2$ | 33.6 | 43.6 |
| Compressive strength 28 d | N/mm$^2$ | 40.0 | 46.9 |

## *2.2. Influence of PCE polymers on cement grinding efficiency*

Grinding aids have been developed to improve the production efficiency of cement grinding plants, the last production step in cement manufacturing. In addition, these products enhance the granulometry as well as powder flowability of the finished cement.

**Characteristics & Mechanism**: Grinding aids are based on substances of high polarity that lead to a better particle dispersion due to the saturation of the surface charges. The successful use of PCE polymers in modern concrete technology as powerful superplasticisers and high range water reducers has led the way to use these polymers also in the cement grinding process. PCE polymers are able to further improve the performance of traditional amino alcohol and glycol-based grinding aids (6). The mechanism of grinding aids is displayed in Figure 2.

Table 2

RELATIVE ENVIRONMENTAL PERFORMANCE IMPROVEMENT OF MIX II COMPARED TO MIX I

| Impact category | Mix I | Mix II | Relative improvement |
|---|---|---|---|
| Abiotic Depletion (elements) [kg Sb-Equiv.] | 0.00048 | 0.00039 | 19% |
| Abiotic Depletion (fossil) [MJ] | 1205 | 1072 | 11% |
| Acidification Potential [kg SO2-Equiv.] | 0.49 | 0.42 | 14% |
| Eutrophication Potential) [kg Phosphate-Equiv.] | 0.085 | 0.074 | 13% |
| Global Warming Potential (100 a) [kg CO2-Equiv.] | 295 | 243 | 18% |
| Human Toxicity Potential [kg DCB-Equiv.] | 10.49 | 9.35 | 11% |
| Ozone Layer Depletion Potential [g R11-Equiv.] | 0.0062 | 0.0052 | 16% |
| Photochem. Ozone Creation Potential [kg Ethene-Equiv.] | 0.046 | 0.041 | 11% |
| Primary energy demand [MJ] | 1481 | 1309 | 12% |
| Eco-indicator 99 (Hierarchist ) [points] | 5.5 | 4.8 | 13% |

The saturation of surfaces reduces agglomeration of particles (a). The prevention of coating of the mill internals results in an intensified impact of the colliding balls and enhanced grinding efficiency (b). Particles that are treated with grinding aids are better dispersed when entering the separator. This increases the separator efficiency and results in a more favourable particles size distribution with lower content of over-ground particles (c).

**LCA of different grinding setups**: A life cycle assessment of three cement grinding setups has been calculated. The results have been

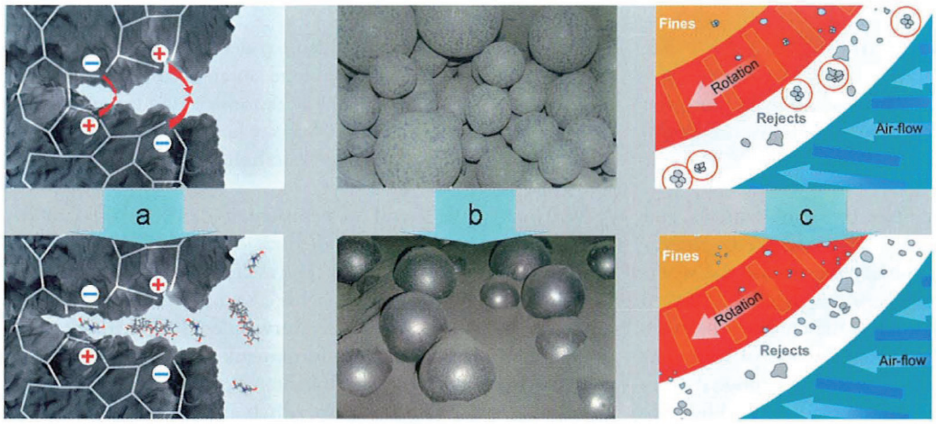

Fig. 2. Mechanism of grinding aids: a) saturation of surface charges, b) prevention of coating, c) dispersion in the separator (6)

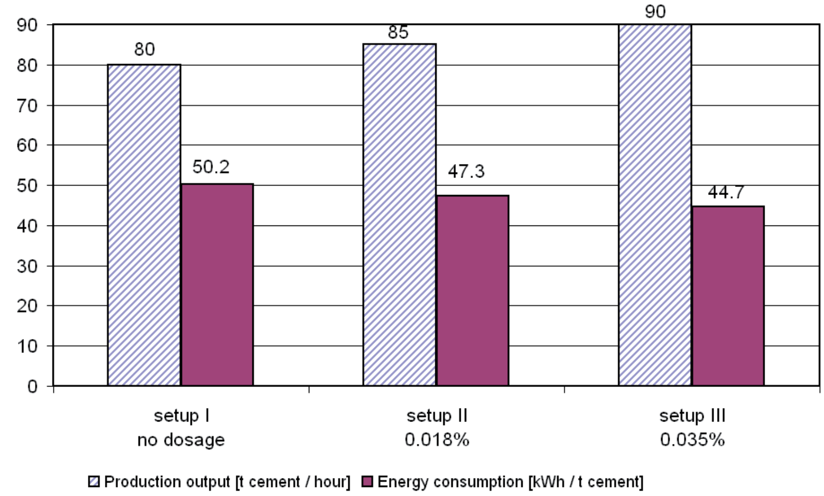

Fig. 3. Mill output and energy consumption related to grinding aid dosage

derived from trials in a cement plant. The setups differ in the dosage of the PCE polymer based grinding aid. Production output and energy consumption have been measured for each setup (Figure 3). The functional unit of the LCA is one ton of ground cement.

The calculation of the LCA has been performed in the same way as in the mix design case study. For the grinding aid, all raw materials, production and packaging processes have been taken into account. An average European power mix has been assumed for the electricity (EU-15 Power grid mix PE).

The relative environmental performance of the different grinding setups has been calculated (Table 3). For the impact categories "Abiotic Depletion (elements)" and "Human Toxicity Potential", setup I has a better environmental performance than the setups with grinding aid dosage. For all other impact categories, the environmental performance is better for the setups with grinding aid dosage. For these impact categories, environmental performance increases with higher dosage and higher energy savings. Considering the Eco-indicator 99 score, the setup with the highest dosage of grinding aid can be regarded as the best option regarding environmental performance. The environmental impact of the grinding aid is more than offset by the reduction in energy consumption.

### *2.3. Conclusion*

Concrete is the most widely used construction material in the world. The ever rising demand for concrete requires therefore continuous environmental improvement at all production stages. The use of PCE polymers based products offers different opportunities to contribute to this improvement. Concluding on the performed LCA calculations, PCE polymers based products allow for overall environmental improvements of cement grinding and concrete mix design. The environmental impacts associated with the use of PCE polymer based products are more than offset by the savings in cement and electricity these products allow for.

Table 3

RELATIVE COMPARISON OF DIFFERENT GRINDING SETUPS REGARDING IMPACT CATEGORIES

| Impact category | 1 kg grinding aid (GA) | 1 kWh electricity (EU-mix) | Setup I 50 kWh no GA | Setup II 47.3 kWh 180 g GA | Setup III 44.7 kWh 350 g GA |
|---|---|---|---|---|---|
| Abiotic Depletion (elements) [g Sb-Equiv.] | 0.002849 | 0.000041 | 100% | 119% | 138% |
| Abiotic Depletion (fossil) [MJ] | 26.65 | 5.14 | 100% | 96% | 93% |
| Acidification Potential [kg $SO_2$-Equiv.] | 0.0043 | 0.0026 | 100% | 95% | 90% |
| Eutrophication Potential) [kg Phosphate-Equiv.] | 0.001910 | 0.000122 | 100% | 100% | 100% |
| Global Warming Pot.(100 a) [kg $CO_2$-Equiv.] | 1.16 | 0.53 | 100% | 95% | 91% |
| Human Toxicity Potential [kg DCB-Equiv.] | 8.628 | 0.037 | 100% | 177% | 251% |
| Ozone Layer Depletion Pot. [g R11-Equiv.] | 0.000081 | 0.000149 | 100% | 94% | 89% |
| Photochem. Ozone Crea. Pot. [kg Ethene-Equiv.] | 0.00072 | 0.00014 | 100% | 96% | 93% |
| Primary energy demand [MJ] | 29.94 | 11.71 | 100% | 95% | 91% |
| Eco-indicator 99 (Hierarichst) [points] | 0.047 | 0.019 | 100% | 95% | 91% |

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