Innovations in Chemical Admixture Technology as Related to Sustainability, Part 2

ACI Spring 2012 Convention
March 18 – 21, Dallas, TX

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Influence of Polycarboxylate Ether Polymers (PCE) on Sustainability in Concrete Production

Presentation by –
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ACI- Spring Convention, Dallas, March 20th, 2012

Objective

- This presentation examines how PCE polymers influence the environmental footprint of concrete at different stages of production process.
- Effects of PCE polymers in Concrete Production and Cement Grinding were analyzed.
- Life Cycle Assessment (LCA) techniques were used to assess impacts associated with the use of PCE polymers.

Contents

- Introduction
- Life Cycle Assessment (LCA)
- Influence of PCE’s on Concrete Mix Design
- Influence of PCE’s on Cement Grinding
- Conclusion
Concrete is a building material with a remarkable product performance in terms of Durability and Technical Solutions, and Concrete Admixtures are part of this successful concept!

Concrete Admixtures are a relevant part to achieve a significant Energy reduction of the concreting Process. Source wise Admixtures play and have an important task in prospect of Sustainability.

Concrete Admixtures and Sustainability

**Concrete Admixtures and Sustainability**

**Concrete Admixtures**

- Durability
  - Reduce Porosity
  - HRWR
  - Improve Frost Resist.
  - AEA & SF
  - Minimize Shrinkage
  - SRA

- Solution
  - Columns
  - Concrete versus Steel
  - Structural Slab
  - No Competition
  - Pervious Concrete
  - Concrete versus Asphalt

**Energy**

- Optimize Mix Design
- Reduce Energy Time
- Reduce Energy Temp
- Reduce Stress
- Accelerators

**Efficiency**

- Recycling Aggregate
- Safe Ingredients
- Health and safety
- Alternative Materials
- Crude oil versus Renewable

**Performance**

- Reduce Permeability
- Improve Frost Resist
- AEA & SF
- Minimize Shrinkage

**Strategies for Environmental Improvement**

- Energy efficiency in production processes
- Alternative fuel use for making clinker
- Clinker substitution by supplementary or complementary cementing materials
- Carbon capture and storage (CCS)
- Optimization of concrete mix design

**Life Cycle Assessment (LCA)**

- LCA is a method to quantify and evaluate potential environmental impacts throughout a product’s life cycle

  - The main purpose of LCA is to improve the environmental impacts of products and activities by guiding the decision making process.

  - LCA provides comprehensiveness in two respects:
    - Takes into account all relevant life cycle aspects of a product
    - Analyses different environmental impact categories
Life Cycle Assessment (LCA)

- In this study, in order to compare different options regarding environmental footprints, LCA techniques were used to assess the impacts associated with the use of PCE polymers.

LCA were run on:
1. Concrete Mix Design
2. Cement Grinding

Life Cycle Assessment (LCA)

- Concrete mixes were modeled in the software, GaBi.
- Datasets for modeling were retrieved from commercial data bases (European Reference Life Cycle Database, PE International and ecoinvent).
- Impact assessment on inventory data was calculated following CML 2001 and Eco-indicator 99 methods.
- LCA was performed by our Corporate Product Sustainability Group.

CML 2001

<table>
<thead>
<tr>
<th>Impact Categories Assessed</th>
<th>Meaning/Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abiotic depletion</td>
<td>Reduction in non renewable resources i.e. fossil fuels, metals, minerals etc.</td>
</tr>
<tr>
<td>Acidification Potential</td>
<td>Acidification of soil and water due to pollutants resulting in new pH and damage to ecosystem</td>
</tr>
<tr>
<td>Eutrophication Potential</td>
<td>Eutrophication means enrichment in nutrients. When effects are undesirable it is considered a form of pollution</td>
</tr>
<tr>
<td>Global Warming Potential</td>
<td>Sum of emission of greenhouse gases</td>
</tr>
<tr>
<td>Human Toxicity Potential</td>
<td>HTP is calculated by adding the releases, which are toxic to humans, to three different media, i.e. air, water and soil</td>
</tr>
<tr>
<td>Ozone Depletion Potential (ODP)</td>
<td>The relative amount of degradation to the ozone layer that can be caused</td>
</tr>
<tr>
<td>Photochem. Ozone Creation Potential</td>
<td>Indicator of ability of a VOC to contribute to photochemical ozone formation. Harmful for humans and vegetation</td>
</tr>
<tr>
<td>Primary Energy Demand</td>
<td>Quantity of energy drawn from various sources without any anthropogenic change</td>
</tr>
</tbody>
</table>

Eco-Indicator 99

- Damage to mineral and fossil resources: 20%
- Damage to Ecosystem Quality: 40%
- Damage to Human Health: 40%

Eco-indicator 99
The Concrete Admixtures LCA Model

Contents
- Introduction
- Life cycle assessment
  - Influence of PCE’s on concrete mix design
  - Influence of PCE’s on cement grinding
- Conclusion

Test Setup – Case Study I
- LCA were conducted on 2 concrete mixes with same w/c
- Mix I (Control), Mix II (PCE admixture)
- Functional unit of LCA was 1 m³ of concrete
- For Mix II, all raw materials, production processes and packaging of the PCE admixture was taken into account.

Mix Design I (Control)

<table>
<thead>
<tr>
<th>Mix Design</th>
<th>Quantity, kg/m³ (lbs/cyd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>350 (590)</td>
</tr>
<tr>
<td>Coarse Aggregates</td>
<td>1092 (1841)</td>
</tr>
<tr>
<td>Fine Aggregates</td>
<td>763 (1318)</td>
</tr>
<tr>
<td>Water</td>
<td>182 (307)</td>
</tr>
<tr>
<td>Admixture</td>
<td>0.00</td>
</tr>
<tr>
<td>W/Cm</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Case Study I: Mix Design

<table>
<thead>
<tr>
<th>Component</th>
<th>MA, kg</th>
<th>kg MJ</th>
<th>MJ %</th>
<th>kg CO₂</th>
<th>CO₂ %</th>
<th>% weight</th>
<th>% MJ</th>
<th>% CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregates</td>
<td>0.053</td>
<td>0.0048</td>
<td>1.092</td>
<td>0.24</td>
<td>4.4%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>0.081</td>
<td>0.0068</td>
<td>728</td>
<td>89.2%</td>
<td>6.4%</td>
<td>97.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>0.01</td>
<td>0.0006</td>
<td>725</td>
<td>9.4%</td>
<td>0.1%</td>
<td>97.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement²</td>
<td>3.59</td>
<td>0.85</td>
<td>1.258</td>
<td>14.9%</td>
<td>89.2%</td>
<td>97.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Admixture³</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) Inventory of Carbon & Energy v2.0 University of Bath
2) WBCSD Cement Sustainability Initiative 2009
3) EFCA, Environmental Declaration Superplasticizers
Comparison of Concrete Mixes

Mix I – Control
Mix II – With PCE admixture

<table>
<thead>
<tr>
<th>Mix Design</th>
<th>Quantity, kg/m³ (lbs/cyd)</th>
<th>Difference, kg/m³ (lbs/cyd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>350(590) 280(472) -70(118)</td>
<td></td>
</tr>
<tr>
<td>Coarse Aggregates</td>
<td>1092(1843) 1145(1930) +53 (88)</td>
<td></td>
</tr>
<tr>
<td>Fine Aggregates</td>
<td>782(1318) 830(1399) +48 (81)</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>182(307) 196(329) -14 (22)</td>
<td></td>
</tr>
<tr>
<td>HRWR (PCE based)</td>
<td>3.36(5.66) 3.36(5.66) -</td>
<td></td>
</tr>
<tr>
<td>W/Cm</td>
<td>0.52 0.52 -</td>
<td></td>
</tr>
</tbody>
</table>

Concrete mixes I and II with:
- same workability
- same w/c

Results – Life Cycle Assessment

Mix Design Quantity, kg/m³ (lbs/cyd) Difference, kg/m³ (lbs/cyd)

<table>
<thead>
<tr>
<th>CML 2001</th>
<th>Mix I</th>
<th>Mix II</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Depletion (elements) [kg Sb-Equiv.]</td>
<td>0.0005</td>
<td>0.0004</td>
<td>19%</td>
</tr>
<tr>
<td>Acid Depletion (fossil) [MJ]</td>
<td>1204.52</td>
<td>1057.60</td>
<td>12%</td>
</tr>
<tr>
<td>Acidification Potential [kg SO2-Equiv.]</td>
<td>0.44</td>
<td>0.42</td>
<td>5%</td>
</tr>
<tr>
<td>Eutrophication Potential [kg Phosphate-Equiv.]</td>
<td>0.28</td>
<td>0.27</td>
<td>4%</td>
</tr>
<tr>
<td>Global Warming Potential (100 years) [kg CO2-Equiv.]</td>
<td>215.48</td>
<td>218.12</td>
<td>13%</td>
</tr>
<tr>
<td>Human Toxicity Potential [HTP inf.] [kg DCB-Equiv.]</td>
<td>10.49</td>
<td>9.17</td>
<td>13%</td>
</tr>
<tr>
<td>Ozone Layer Depletion Potential [g R11-Equiv.]</td>
<td>0.01</td>
<td>0.01</td>
<td>16%</td>
</tr>
<tr>
<td>Photochem. Ozone Creation Potential [kg Ethene-Equiv.]</td>
<td>0.05</td>
<td>0.04</td>
<td>12%</td>
</tr>
<tr>
<td>Primary energy demand (net cal. value) [MJ]</td>
<td>1481.00</td>
<td>1262.85</td>
<td>13%</td>
</tr>
<tr>
<td>Eco-Indicator 99</td>
<td>5.50</td>
<td>4.74</td>
<td>14%</td>
</tr>
</tbody>
</table>

Results Analysis – Case Study I

- Mix II has an overall better environmental performance than Mix I in every impact category
- In CML 2001, the relative improvement is between 12-19% for all impact categories
- Use of PCE based admixtures can reduce the environmental impact of concrete by cement reduction.

Case Study II: Mix Design

<table>
<thead>
<tr>
<th>Mix Design</th>
<th>Quantity, kg/m³ (lbs/cyd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>300 506</td>
</tr>
<tr>
<td>Coarse Aggregates</td>
<td>1170 1972</td>
</tr>
<tr>
<td>Fine Aggregates</td>
<td>780 1315</td>
</tr>
<tr>
<td>Water</td>
<td>150 253</td>
</tr>
<tr>
<td>W/Cm</td>
<td>0.5 0.5</td>
</tr>
</tbody>
</table>

Case Study II

- Environmental impact categories assessed for 1m³ of concrete:
  - Eutrophication Potential
  - Ozone Depletion Potential
  - Global Warming Potential
  - Primary Energy Demand

Test Results

Eutrophication Potential
- Lignin
- SMF/ SNF
- PCE

Ozone Depletion Potential
- Lignin
- SMF/ SNF
- PCE
Results Analysis – Case Study II

- PCE admixtures had smaller material intensity since lower amount of material and packaging goods are required.
- PCE admixtures contain lower amount of embodied energy to produce a product with the same effect as compared to other technologies.
- Environmental impacts of PCE admixtures are lower than other technologies.

Introduction

- **Cement manufacture** is a highly technical process in which every part has a decisive impact on the product quality as well as on economical and ecological production parameters.
- The **cement grinding process** is the final chance to adjust the cement quality to meet the demands set by relevant standards and cement customers.
Working principle grinding aids (GA):

GA support the cracking

Ensured cracking of particles leads to a faster grinding.

GA reduce coating of mill equipment

Use of GA reduces coating on grinding media which intensifies the impact of the colliding balls = enhanced grinding efficiency.

GA reduce re-agglomeration phenomena

Grinding aids are based on substances of high polarity which neutralize the electric charges.

The resulting lower attraction forces lead to a better particle dispersion and cause different effects.

GA improve separator efficiency

Improved separator efficiency increases production rate.

Working principle of PCE grinding aids (GA):

GA support the cracking

PCE transported into the crack by gas diffusion.

Traditional and new Technologies

Proven traditional technologies for grinding aids are amines and glycols.

PCE powered grinding aid technology is able to improve the performance of traditional amine and glycol based grinding aids.
PCE powered GA increases the production significantly.

Higher mill output / reduced specific energy with PCE powered GA

Specific energy consumption of mill drive without grinding aid (blank):
\[ p = \frac{5.140 \text{ kW}}{108 \text{ t/h}} = 47.6 \text{ [kWh/t]} \]

Specific energy consumption of mill drive with trad. Amine based grinding aid:
\[ p = \frac{5.140 \text{ kW}}{122 \text{ t/h}} = 42.1 \text{ [kWh/t]} \]

Specific energy consumption of mill drive with PCE based GA:
\[ p = \frac{5.140 \text{ kW}}{129 \text{ t/h}} = 39.8 \text{ [kWh/t]} \]

PCE powered GA reduces the specific energy consumption significantly!

Cement additives with enhancing effect on the grinding process: Technologies

\begin{itemize}
  \item PCE
  \item TEA
  \item DEG
\end{itemize}

Dosage of GA, % by wt. of cement

Maximized Mill Production
Enhanced Strength Development
Improved particle size distribution
Higher clinker replacement
Improved powder flowability/ bulk density
Improved concrete workability

Test Set up
\begin{itemize}
  \item LCA was conducted on 3 cement grinding setups.
  \item First setup was the Control (no grinding aid), the next two setups had a different dosage of the PCE powered grinding aid.
  \item Production output and energy consumption were measured for each setup.
  \item The functional unit of each LCA is one ton of ground cement.
  \item For the grinding aid, all raw materials, production and packaging processes had been taken into account.
\end{itemize}

Test Results - Efficiency of grinding process

\begin{itemize}
  \item Setup I - no dosage
  \item Setup II - 0.018%
  \item Setup III - 0.036%
\end{itemize}

\begin{itemize}
  \item Energy consumption [kWh / t cement]
  \item Production output [t cement / hour]
\end{itemize}

\begin{itemize}
  \item +5.78%
  \item +6.25%
  \item +12.5%
  \item -5.78%
  \item -11.75%
\end{itemize}
Results – Life Cycle Assessment

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Setup I (No GA)</th>
<th>Setup II (0.016%)</th>
<th>Setup III (0.035%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eco-indicator 99</td>
<td>100%</td>
<td>95%</td>
<td>91%</td>
</tr>
</tbody>
</table>

Results Analysis
- Considering Eco-indicator 99 score, Setup III, with the highest dosage of PCE grinding aid has the best environmental performance.
- PCE based grinding aids can improve the environmental impacts of cement by reduction in energy consumption.

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- Conclusion

Conclusion
- PCE polymer based products offers different opportunities to improve the environmental footprint of concrete at all stages of concrete production.
- Based on the LCA calculations, PCE polymers allow for overall environmental improvement in cement grinding and concrete mix design.
- New developments drive the need for PCE polymers:
  - Ultra High Performance Concrete
  - Blended cements
  - Recycled aggregates
  - High SCM replacement levels in cement & concrete

Thank you
Questions?