Development of green self compacting concrete containing low clinker cement and calcareous fly ash

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Introduction

Green Concrete - concrete that has had extra steps taken in the mix design and placement to insure a sustainable structure and a long life cycle with a low maintenance surface. E.g. energy saving, CO$_2$ emissions, waste water.

- Optimized use of materials and mix design
- Enhanced workability in fresh state, best by the aim for obtaining self-compacting concrete (SCC).
- Enhanced durability and service life

The paper presents a concept of green self-compacting concrete (SCC), emphasizing mostly the minimization of the amount of clinker in concrete and obtainment of their low hardening temperature. The main purpose of this SCC concrete are massive and semi-massive constructions, as well as the hot weather concreting.
**Self-compacting concrete**

SCC mixtures is designed for a combination of flowability, ability to pass through and around reinforcement without blockage, ability to remove air from the mix and resistance to segregation.

- $w/c < 0.50$ ($w/b < 0.4$)
  - Water: $160 \div 200$ dm$^3$/m$^3$
  - Fine fraction (0-0.125 mm): $450 \div 600$ kg/m$^3$

- Segregation resistance, bleeding

- **Paste volume**: $300 \div 400$ dm$^3$/m$^3$
  - Segregation resistance, bleeding

- **Sand content**: $40 \div 50\%$ of total aggregate
  - Segregation resistance

- **Aggregate – coarse**, max 16 mm
  - Segregation resistance

- **Effective superplasticizer**
  - Flowability

- **Viscosity enhancing admixture**
  - Segregation resistance, bleeding
Concrete for massive construction

Massive concrete composition is designed so that the amount of heat generated by cement hydration is minimized.

Constituents selection (cement, admixtures and additives)
- low hardening temperature, low hydration heat

Low cement content, low content of finest fraction
- Lower hardening temperature and sensibility of concrete for cracking

Low water content
- Lower shrinkage, lower setting, lower concrete cracking

\[ w/c > 0,5 \]
- reduced hardening temperature

Sand content 30 – 35%
Aggregate – max. 32 mm
- Lower external stress, technology
- Thermal conduction and thermal expansion coefficients
Green, low hydration SCC

- \( w/c < 0.50 \) (\( w/b < 0.4 \))
- Water - 160÷200 dm\(^3\)/m\(^3\)
- Fine fraction (0-0.125 mm) - 450÷600 kg/m\(^3\)

Segregation resistance, bleeding

- Paste volume - 300÷400 dm\(^3\)/m\(^3\)
- Segregation resistance, bleeding

- Sand content - 40÷50% of total aggregate
- Segregation resistance

- Aggregate - coarse, max 16 mm
- Segregation resistance

- Effective superplasticizer
- Flowability

- Viscosity enhancing admixture
- Segregation resistance, bleeding

Constituents selection (cement, admixtures and additives)
- Low hardening temperature, low hydration heat

Low cement content, low content of finest fraction
- Lower hardening temperature and sensibility of concrete for cracking

Low water content
- Lower shrinkage, lower setting, lower concrete cracking

- \( w/c > 0.5 \)
- Reduced hardening temperature

Sand content 30 – 35%
- Aggregate - max. 32 mm
- Lower external stress, technology
- Thermal conduction and thermal expansion coefficients

- \( w/c = 0.35 ÷ 0.60 \) (\( w/b = 0.35 ÷ 0.45 \))
- Water - 160÷200 dm\(^3\)/m\(^3\)
- Fine fraction (0-0.125 mm) - 450 kg/m\(^3\)

Paste volume - 300 dm\(^3\)/m\(^3\)

Low heat cement (CEM III/B)
+ Mineral admixtures (CFA, quartz and limestone mill)

Aggregate – coarse, max 16 mm

Effective superplasticizer (retarding effect)
## SCC proportioning

<table>
<thead>
<tr>
<th>Ingredients [kg/m³]</th>
<th>B0</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I 52,5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>451</td>
</tr>
<tr>
<td>CEM III/B 42,5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>306</td>
</tr>
<tr>
<td>CFA (ground)</td>
<td></td>
<td></td>
<td></td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>Quartz powder</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>135</td>
</tr>
<tr>
<td>Limestone powder</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>125</td>
</tr>
<tr>
<td>Sand 0-4 mm</td>
<td>800</td>
<td>969</td>
<td>998</td>
<td>997</td>
<td>880</td>
</tr>
<tr>
<td>Coarse 4-11 mm</td>
<td>437</td>
<td>363</td>
<td>372</td>
<td>374</td>
<td>420</td>
</tr>
<tr>
<td>Coarse 8-16 mm</td>
<td>538</td>
<td>451</td>
<td>468</td>
<td>464</td>
<td>490</td>
</tr>
<tr>
<td>Water</td>
<td>171</td>
<td>193</td>
<td>151</td>
<td>158</td>
<td>160</td>
</tr>
<tr>
<td>SP</td>
<td>3.91</td>
<td>2.90</td>
<td>7.78</td>
<td>5.45</td>
<td>5.28</td>
</tr>
<tr>
<td>(w_{\text{eff}}/(c+a))</td>
<td>0.38</td>
<td>0.63</td>
<td>0.44</td>
<td>0.41</td>
<td>0.42</td>
</tr>
<tr>
<td>(w_{\text{eff}}/c)</td>
<td>0.38</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
</tr>
<tr>
<td>Cement paste volume, dm³</td>
<td>320</td>
<td>294</td>
<td>270</td>
<td>293</td>
<td>291</td>
</tr>
<tr>
<td>Clinker content in concrete</td>
<td>428</td>
<td>77</td>
<td>60</td>
<td>62.5</td>
<td>63</td>
</tr>
</tbody>
</table>
Testing methods

- Setting time of concrete - ultrasonic method - modified Schleibinger Vikasonik system.
- Development of concrete temperature - cubic samples 250 mm on a side insulated using styrofoam coating.
- Early shrinkage – modified Schleibinger TLS apparatus on samples 10x10x50 cm during 24 hours from the moment of placement.
- Compressive strength after 2, 7 and 28 days - EN 12390-3.
- Hydration heat - for binders and admixtures used in tested concretes hydration head and hydration kinetics were measured using isomeric calorimeter TamAir produced by TA Instruments.
# Test results

<table>
<thead>
<tr>
<th>Property</th>
<th>B0</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow, mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>after 5 min</td>
<td>705</td>
<td>680</td>
<td>650</td>
<td>670</td>
<td>695</td>
</tr>
<tr>
<td>after 60 min</td>
<td>680</td>
<td>670</td>
<td>600</td>
<td>660</td>
<td>670</td>
</tr>
<tr>
<td>Flow time $T_{500/5}$, s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>after 5 min</td>
<td>2.3</td>
<td>2.7</td>
<td>6.0</td>
<td>5.2</td>
<td>5.4</td>
</tr>
<tr>
<td>after 60 min</td>
<td>2.7</td>
<td>2.9</td>
<td>7.4</td>
<td>6.7</td>
<td>7.0</td>
</tr>
<tr>
<td>Air content, %</td>
<td>2.1</td>
<td>1.5</td>
<td>1.3</td>
<td>2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Setting time of concrete, h:min</td>
<td>6:36</td>
<td>10:04</td>
<td>12:00</td>
<td>10:12</td>
<td>9:43</td>
</tr>
<tr>
<td>Shrinkage after 24 h, mm/m</td>
<td>0.93</td>
<td>1.03</td>
<td>1.39</td>
<td>1.36</td>
<td>1.22</td>
</tr>
<tr>
<td>Maximal temperature, °C</td>
<td>72.9</td>
<td>34.8</td>
<td>32.2</td>
<td>30.0</td>
<td>32.2</td>
</tr>
<tr>
<td>Time of maximal temperature, h:min</td>
<td>29:54</td>
<td>36:55</td>
<td>51:28</td>
<td>45:56</td>
<td>43:56</td>
</tr>
<tr>
<td>Compressive strength, MPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>after 1 day</td>
<td>34.3</td>
<td>2.27</td>
<td>4.9</td>
<td>1.2</td>
<td>1.98</td>
</tr>
<tr>
<td>after 7 days</td>
<td>58.6</td>
<td>25.4</td>
<td>36.0</td>
<td>31.0</td>
<td>29.4</td>
</tr>
<tr>
<td>after 28 days</td>
<td>77.8</td>
<td>41.4</td>
<td>48.3</td>
<td>44.8</td>
<td>42.5</td>
</tr>
</tbody>
</table>
Properties of SCC

\[ \text{B0} - \text{CEM I} \]
\[ \text{B1} - \text{CEM III/B} \]
\[ \text{B2} - \text{CEM III/B + CFA} \]
\[ \text{B3} - \text{CEM III/B + Q} \]
\[ \text{B4} - \text{CEM III/B + L} \]

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<td>5.28</td>
</tr>
</tbody>
</table>
Settig time and shrinkage

**B0** – CEM I
**B1** – CEM III/B
**B2** – CEM III/B + CFA
**B3** – CEM III/B + S
**B4** – CEM III/B + L

**Setting time of concrete, h:min**

**Shrinkage after 24 hours, mm/m**
Temperature kinetics

**B0** – CEM I  
**B1** – CEM III/B  
**B2** – CEM III/B + CFA  
**B3** – CEM III/B + S  
**B4** – CEM III/B + L
Compressive strength

\[ \begin{align*}
B0 & = \text{CEM I} \\
B1 & = \text{CEM III/B} \\
B2 & = \text{CEM III/B + CFA} \\
B3 & = \text{CEM III/B + S} \\
B4 & = \text{CEM III/B + L} \\
\end{align*} \]
Summary

It was demonstrate that by optimizing materials and mix composition green SCC, characterized by low hardening heat can be obtained.

SCC are characterized by the low content of clinker, amounting from 60 to 77 kg/m³ and good strength properties. It can be also assumed that those concretes, due to the high content of blast-furnace slag, will be characterized by the adequate durability, however it requires further experimental verification.

Ground calcerous fly ash can be used for self-compacting concrete, without negatively affecting its properties after hardening.