THE REACTIVITY OF WOODY ASH IN COMPARISON WITH SLAG

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Introduction

Content
1) Introduction
2) Experimental part
3) Results of testing and discussion
4) Conclusions and future work

WiB Microlab
1) Introduction
2) Experimental part
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4) Conclusions and future work

• Experimental
  - Set-up
  - Slag comparison
  - Sample preparation
  - Thermogravimetric analysis

Results
  - Chemically bounded water
  - Calcium hydroxide
  - Pore volume
  - Compressive strength
## Experimental: Plan

<table>
<thead>
<tr>
<th>Material</th>
<th>Replacement Rates</th>
<th>w/b</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I 52.5 R</td>
<td>3, 5, 10, 20, 30, 40, 60, 80, 95%</td>
<td>0.35, 0.45</td>
</tr>
<tr>
<td>Slag 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drinking water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEM I 52.5 R</td>
<td>10, 20, 40, 60, 80, 100%</td>
<td>0.45</td>
</tr>
<tr>
<td>Slag 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drinking water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEM I 42.5 N</td>
<td>10, 15, 20, 100%</td>
<td>0.5</td>
</tr>
<tr>
<td>Woody ash</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drinking water</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stop after 1 day, 7, 14, 28, 56, 365 days
Experimental: Slag comparison

<table>
<thead>
<tr>
<th>Components [mass %]</th>
<th>Slag 1</th>
<th>Slag 2</th>
<th>WA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>42.44</td>
<td>41.22</td>
<td>41.3</td>
</tr>
<tr>
<td>SiO₂</td>
<td>35.85</td>
<td>36.18</td>
<td>26.7</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>11.38</td>
<td>12.13</td>
<td>4.72</td>
</tr>
<tr>
<td>MgO</td>
<td>6.00</td>
<td>7.23</td>
<td>7.5</td>
</tr>
<tr>
<td>S²⁻</td>
<td>1.25</td>
<td>1.06</td>
<td></td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.78</td>
<td>0.74</td>
<td>0.34</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.37</td>
<td>0.55</td>
<td>7.86</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.22</td>
<td>0.39</td>
<td>1.95</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.41</td>
<td>0.39</td>
<td>2.04</td>
</tr>
<tr>
<td>Fe</td>
<td></td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>MnO</td>
<td>0.255</td>
<td></td>
<td>0.63</td>
</tr>
<tr>
<td>Mn</td>
<td></td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>Cl⁻</td>
<td>0.014</td>
<td>0.04</td>
<td>0.054</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.17</td>
<td>0.04</td>
<td>0.68</td>
</tr>
<tr>
<td>Mn₂O₃</td>
<td>0.283</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- CaO/SiO₂ (Slag 1) > CaO/SiO₂ (Slag 2)
- Al₂O₃ (Slag 2) > Al₂O₃ (Slag 1)
- MgO (Slag 2) > MgO (Slag 1)

Slag 2 is finer

<table>
<thead>
<tr>
<th>Blaine value [cm²/g]</th>
<th>Slag 1</th>
<th>Slag 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4000</td>
<td>4600</td>
</tr>
</tbody>
</table>

\[d_{50}(WA) = 146\ \text{um}\]
Experimental: Sample preparation

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- 1) Mixing
- 2) Storing
- 3) Hand-milling
- 4) Treating with acetone
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Before you start: When / How to stop hydration?
Hydration Stoppage: Different Techniques

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Experimental: Thermogravimetric analysis

- Corundum crucible filled with 40 - 50 mg sample powder
- Nitrogen used as inert gas

• Temperature programme:
  - 30 minutes at 40 °C and
  - Heating to 1000 °C with a constant heating rate of 20 °C per minute
Results: Thermogravimetric analysis

Ca(OH)$_2$ disintegrates between 400 – 500 °C

Ca(OH)$_2$ → CaO + H$_2$O

Chemically bounded water

Ca(OH)$_2$
Results: Chemically bounded water (BW)

Chemically bounded water Slag 1 (w/b = 0.45)

- BW removed from 40 - 600 °C
- Largest increase from day 1 to 7
- Decrease with higher slag content
- (Slag > 20 mass % and early age)

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Results: Calcium hydroxide (CH)

- CH decomposes from 360 - 550 °C (tangential method was used)
- CH content decreases with increasing slag content
- CH content increases with time
- w/b = 0.35 lower CH content when slag content ≤ 20 %
Results: Consumption of calcium hydroxide

Consumption of Ca(OH)$_2$ Slag 1 (w/b = 0.45)

Consumption = Ca(OH)$_2$ produced by cement (reference) - Ca(OH)$_2$ measured
Results: Calcium hydroxide slag (S) versus Woody ash (WA)

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Results: Calcium hydroxide (CH)

- Logarithmic scale
- CH content increasing linearly with log of time
- Slag 2 slightly higher CH content
Results: Calcium hydroxide regression model

Regression model:

$$CH = \beta_0 + \beta_1 \cdot Slag + \beta_2 \cdot \log(t)$$

$CH = \text{Ca(OH)}_2 \ [g / 100g \text{ unhyd. binder}]$

$Slag = \text{slag content of initial mixture [mass \%]}$

$t = \text{hydration time [days]}$

<table>
<thead>
<tr>
<th>Slag</th>
<th>w/b</th>
<th>$\beta_0$</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slag1</td>
<td>0.35</td>
<td>15.56</td>
<td>-0.19</td>
<td>1.66</td>
<td>0.9556</td>
</tr>
<tr>
<td>Slag1</td>
<td>0.45</td>
<td>16.73</td>
<td>-0.22</td>
<td>1.83</td>
<td>0.9462</td>
</tr>
<tr>
<td>Slag2</td>
<td>0.45</td>
<td>18.14</td>
<td>-0.22</td>
<td>1.45</td>
<td>0.9604</td>
</tr>
</tbody>
</table>

Results up to 28 days included.
- Pore volume measured with pycnometer
- Decreasing pore volume with time
- Porosity increases for slag content > 30 %
Additional results: Pore volume

- After 1 day higher porosity with increasing exchange rate

- After 56 days the minimum calculated porosity is with 40% exchange rate
Additional results: Compressive strength

Compressive strength Slag 1 (w/b = 0.35)

Compressive strength Woody ash (w/b = 0.5)

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Conclusions

- Ca content of slag and WA are nearly the same

- CH consumption for WA has almost negligible up to 20%

- Reactivity of WA differs from slag

- Pore structure depending on replacement ratio

- For WA replacement rate up to 20% has constant impact on strength
Greetings from Darmstadt!

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THANK YOU FOR YOUR ATTENTION

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Transformation of Wood Biomass Ash into Resilient Construction Composites