High Durability Concrete Using High-Carbon Fly Ash and Pulp Mill Residuals

by

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Center for By-Products Utilization
Durable Concrete in Northern Climates

• Producing durable concrete in a freezing and thawing environment, typically requires the use of air entraining admixtures.

• Typical air-entraining admixtures have limited effectiveness when using high-carbon fly ashes, thus limiting uses for such high-carbon materials.
High-Carbon Ash Materials

• The typical cost of an AEA for concrete is not very expensive, however, the specialty admixtures that are required when using a high-carbon, or variable carbon ash adds a significant cost to concrete produced, which typically make using high-carbon fly ash cost prohibitive.

• In order to recycle the ash effectively in concrete, electric utilities must either install expensive equipment for beneficiation of the ash or dispose of the ash in landfills.
Durable “Green” Concrete

• Incorporate pulp and paper mill residual solids to provide resistance to freezing and thawing resistance for concrete containing high-carbon materials.

• Reduce amounts of high-carbon fly ash and pulp mill residual solids going to landfills.
MATERIALS

• High Carbon (HC) Materials
  • Spent Activated Carbon Sorbent (PI-ACS)
  • High-Carbon Fly Ash (V-HCA)
• Fibrous Residual (Fiber reclaim process) (BR)

• Cement (ASTM Type I), Aggregates (Natural Sand, 19mm Crushed Quartzite), HRWRA, WRA
100X Magnification

Fibrous Residual Source BR

1000X Magnification
<table>
<thead>
<tr>
<th>Property</th>
<th>PI-ACS</th>
<th>V-HCFA</th>
<th>ASTM C 618 Class C / Class F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness, amount retained on 45-µm (No. 325) sieve (mass %)</td>
<td>3.5</td>
<td>46.9</td>
<td>34 max.</td>
</tr>
<tr>
<td>Strength activity (% of Control)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 days</td>
<td>123.4</td>
<td>59.8</td>
<td>75 min. at either 7 or 28 days</td>
</tr>
<tr>
<td>28 days</td>
<td>130.5</td>
<td>64.0</td>
<td></td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>2.49</td>
<td>2.12</td>
<td>--</td>
</tr>
</tbody>
</table>
# Chemical Properties – HC Materials

<table>
<thead>
<tr>
<th>Property</th>
<th>PI-ACS</th>
<th>V-HCFA</th>
<th>ASTM Class C</th>
<th>ASTM Class F</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$ (%)</td>
<td>42.5</td>
<td>64.3</td>
<td>70 min.</td>
<td>50 min.</td>
</tr>
<tr>
<td>Calcium oxide, CaO (%)</td>
<td>17.4</td>
<td>4.1</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Sulfur trioxide, SO$_3$ (%)</td>
<td>8.6</td>
<td>0.5</td>
<td>5.0 max</td>
<td>5.0 max</td>
</tr>
<tr>
<td>Loss on ignition at 750ºC (%)</td>
<td>17.4</td>
<td>26.2</td>
<td>6.0 max</td>
<td>6.0 max</td>
</tr>
</tbody>
</table>
Concrete Mixtures

_Eight Concrete Mixtures Produced_

• Reference Mixture
  - Without Residuals, V-HCFA, or PI-ACS

• Four Concrete Mixture With PI-ACS and Residuals

• Three Concrete Mixtures With V-HCFA and Residuals
CONCRETE TESTING

- Fresh Concrete Properties
  - Unit Weight (ASTM C 138)
  - Air Content (ASTM C 237)
  - Slump (ASTM C 143)
  - Temperature (ASTM C 1064)
## Concrete Mixtures – V-HCFA

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Ref-2</th>
<th>V-8</th>
<th>V-9</th>
<th>V-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibrous Residual, BR (mass % of concrete)</td>
<td>0</td>
<td>0.3</td>
<td>0.59</td>
<td>0.88</td>
</tr>
<tr>
<td>Cement, (kg/m³)</td>
<td>349</td>
<td>298</td>
<td>293</td>
<td>289</td>
</tr>
<tr>
<td>V-HCFA, (kg/m³)</td>
<td>0</td>
<td>48</td>
<td>48</td>
<td>47</td>
</tr>
<tr>
<td>BR, (kg/m³)</td>
<td>0</td>
<td>7</td>
<td>14</td>
<td>21</td>
</tr>
<tr>
<td>W/Cm</td>
<td>0.43</td>
<td>0.45</td>
<td>0.46</td>
<td>0.47</td>
</tr>
</tbody>
</table>
# Selected Concrete Properties

V-HCFA

<table>
<thead>
<tr>
<th>Mix No. (BR Content, kg/m³)</th>
<th>Ref-2 (0)</th>
<th>V-8 (7)</th>
<th>V-9 (14)</th>
<th>V-10 (21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Content, (%)</td>
<td>1.0</td>
<td>1.1</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Fresh Concrete Density, (kg/m³)</td>
<td>2440</td>
<td>2420</td>
<td>2390</td>
<td>2440</td>
</tr>
</tbody>
</table>
Fibrous Residuals Mixed in Water
## Concrete Mixtures – PI-ACS

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Ref-2</th>
<th>P-11</th>
<th>P-12</th>
<th>P-13</th>
<th>P-14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibrous Residual, BR (mass % of concrete)</td>
<td>0</td>
<td>0.07</td>
<td>0.29</td>
<td>0.59</td>
<td>0.88</td>
</tr>
<tr>
<td>Cement, (kg/m³)</td>
<td>349</td>
<td>261</td>
<td>260</td>
<td>258</td>
<td>255</td>
</tr>
<tr>
<td>PI-ACS, (kg/m³)</td>
<td>0</td>
<td>86</td>
<td>85</td>
<td>85</td>
<td>84</td>
</tr>
<tr>
<td>BR, (kg/m³)</td>
<td>0</td>
<td>2</td>
<td>7</td>
<td>14</td>
<td>21</td>
</tr>
<tr>
<td>W/Cm</td>
<td>0.43</td>
<td>0.43</td>
<td>0.44</td>
<td>0.43</td>
<td>0.46</td>
</tr>
</tbody>
</table>
## Selected Concrete Properties – PI-ACS

<table>
<thead>
<tr>
<th>Mix No. (BR Content, kg/m³)</th>
<th>Ref-2 (0)</th>
<th>P-11 (2)</th>
<th>P-12 (7)</th>
<th>P-13 (14)</th>
<th>P-14 (21)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air Content (%)</strong></td>
<td>1.2</td>
<td>1.3</td>
<td>0.9</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Fresh Concrete Density, (kg/m³)</strong></td>
<td>2450</td>
<td>2440</td>
<td>2440</td>
<td>2420</td>
<td>2410</td>
</tr>
</tbody>
</table>
CONCRETE TESTING

Hardened Concrete Properties
(3 test specimens tested at each age)

• Compressive Strength (ASTM C 39)
• Resistance to Freezing and Thawing Cycling (ASTM C 666, Procedure A)
• Resistance to Scaling from Exposure to Salt Solution (ASTM C 672)
Compressive Strength – Concrete Containing PI-ACS
Compressive Strength – Concrete Containing V-HCFA
Resistance to Freezing and Thawing – Concrete Containing PI-ACS

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Resistance to Freezing and Thawing – Concrete Containing V-HCFA
Resistance to Salt Scaling – Concrete Containing PI-ACS
Resistance to Salt Scaling – Concrete Containing PI-ACS

Visual Rating

Freezing and Thawing Cycles

Ref-2 (0) P-11 (2) P-12 (7)
P-13 (14) P-14 (21)
Resistance to Salt Scaling – Concrete Containing V-HCFA

Visual Rating

Freezing and Thawing Cycles

Ref-2 (0) V-8 (7) V-9 (14) V-10 (21)
Resistance to Salt Scaling – Concrete Containing V-HCFA
Economic Assessment

• Landfill costs would be reduced.
• ~1.4 million tonnes of pulp mill residual solids are produced each year in Wisconsin.
• In Wisconsin it is estimated that $40 million dollars are wasted each year on landfilling. Although the addition rates appear to be small, if all AEC in Wisconsin contained between 0.5% and 1.0% of residuals up to 90,000 tonnes of residuals in Wisconsin could be recycled. This would save up to $3,000,000 each year in disposal costs.
Summary and Conclusions

• The chemical and physical properties of the PI-ACS and V-HCFA did not meet the requirements of ASTM C618.

• Activity with cement with PI-ACS was very high. This indicates that based upon strength, this material would be a useful material in construction.
Summary and Conclusions

• Although the V-HCFA exhibited lower activity with cement, the ash could also be used in selected concrete construction applications.

• Concrete containing the PI-ACS achieved a higher compressive strength than the reference mixture, particularly at the later ages of 28 and 91 days.
Summary and Conclusions

• All mixtures containing the V-HCFA had a compressive strength that was lower than the reference mixture. As the amount of fibers was increased in the concrete mixtures, the compressive strength decreased, but the difference was less at the later age of 91 days.
Summary and Conclusions

• F/T resistance of concrete containing PI-ACS increased as the amount of BR was increased.

• Concrete containing V-HCFA and BR achieved a higher F/T resistance than the reference mixture. (Highest F/T Resistance - 7 kg/m$^3$ of BR (0.30 mass % of concrete))
Summary and Conclusions

- Concrete with PI-ACS that contained the lowest amounts of BR, 2 kg/m³, Mixture P-11 and Mixture P-12, achieved the highest resistance to salt-scaling.

- Concrete with V-HCFA: The two mixtures with the highest resistance to salt-scaling, had the lowest amounts of BR, 7 kg/m³ (0.30 mass % of concrete), 14 kg/m³ (0.60 mass % of concrete) of residuals.
Summary and Conclusions

• The results of this project show that when pulp and paper mill residuals are used as an additive in concrete, high-carbon coal combustion products can be used in concrete subject to a freezing and thawing environment.
Summary and Conclusions

• This will allow use of high-carbon and variable-carbon coal combustion products in many varied types of concrete construction applications.
ACKNOWLEDGEMENTS

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ACKNOWLEDGEMENTS

THANK YOU
for your interest