Pulp and Paper Mill Fibrous Residuals in Excavatable Flowable Fill

by
Yoon-moon Chun, Tarun R. Naik, and Rudolph N. Kraus

UWM Center for By-Products Utilization
University of Wisconsin - Milwaukee

Presented at the International Conference on Sustainable Construction Materials and Technologies, Coventry, U.K., June 11 - 13, 2007
Pulp and Paper Mill
Wastewater Treatment Residuals

• Solid residue removed from mill wastewater before the water is discharged or reused.
• Removed via a two-step (primary and secondary).
• Usually, dewatered before disposal or beneficial use.
Paper Mill Wastewater Treatment Process
Management of Pulp and Paper Mill Residual Solids

• Approximately 2/3 of the residual solids generated in the USA is either landfilled or burned.
Objectives

- Establish technical and performance benefits of using pulp and paper mill residual solids in flowable slurry.
- Improve setting and long-term strength of flowable slurry.
- Establish optimum mixture proportions for flowable slurry containing residual solids.
Characterization of the Residuals

• Residual solids from two sources were selected.
  – WR: Screening rejects from a pulp mill
  – C1: Waste-water treatment residual from a pulp/paper mill

• Physical and chemical properties determined.
As-received fibrous residual WR
As-received fibrous residual C1
No Pretreatment of Residuals

- The fibrous residuals were used as-received and not “re-pulped.”
Flowable Slurry Laboratory Mixtures

Mixture proportions were established through preliminary mixing and testing of ash- and sand-flowable slurry mixtures containing various amounts of:

- Cement
- Class C fly ash
- Water
- Fibrous residuals
Flowable Slurry Laboratory Mixtures (cont’d)

• Determined effects of amount of residuals on the mixing water demand, flow, and strength of flowable slurry.
## Mixture Proportions and Fresh CLSM Properties

<table>
<thead>
<tr>
<th>Mixture designation</th>
<th>FA-Ref</th>
<th>FA-Ref-2</th>
<th>FA-WR</th>
<th>FA-WR-2</th>
<th>FA-C1</th>
<th>FA-C1-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibrous residual</td>
<td>(None)</td>
<td>(None)</td>
<td>WR</td>
<td>WR</td>
<td>C1</td>
<td>C1</td>
</tr>
<tr>
<td>Cement (kg/m³)</td>
<td>75</td>
<td>179</td>
<td>25</td>
<td>27</td>
<td>21</td>
<td>29</td>
</tr>
<tr>
<td>Class C fly ash (kg/m³)</td>
<td>1213</td>
<td>1612</td>
<td>811</td>
<td>877</td>
<td>692</td>
<td>923</td>
</tr>
<tr>
<td>Sand, SSD (kg/m³)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fibrous residual (kg/m³)</td>
<td>0</td>
<td>0</td>
<td>167</td>
<td>181</td>
<td>285</td>
<td>190</td>
</tr>
<tr>
<td>Water (kg/m³)</td>
<td>496</td>
<td>645</td>
<td>522</td>
<td>456</td>
<td>445</td>
<td>444</td>
</tr>
<tr>
<td>W/Cm</td>
<td>0.39</td>
<td>0.36</td>
<td>0.62</td>
<td>0.50</td>
<td>0.62</td>
<td>0.47</td>
</tr>
<tr>
<td>Flow (mm)</td>
<td>335</td>
<td>415</td>
<td>380</td>
<td>230</td>
<td>235</td>
<td>275</td>
</tr>
<tr>
<td>Air content (%)</td>
<td>0.8</td>
<td>1.2</td>
<td>n. a.</td>
<td>3.1</td>
<td>3.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>1780</td>
<td>2440</td>
<td>1530</td>
<td>1540</td>
<td>1440</td>
<td>1590</td>
</tr>
</tbody>
</table>
Mixing of fly ash slurry mixture (without fibrous residuals)
Water, fibrous residual C1, cement, and fly ash in the mixer
## Mixture Proportions and Fresh CLSM Properties

<table>
<thead>
<tr>
<th>Mixture designation</th>
<th>Sd-Ref</th>
<th>Sd-Ref-2</th>
<th>Sd-WR</th>
<th>Sd-C1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibrous residual</td>
<td>(None)</td>
<td>(None)</td>
<td>WR</td>
<td>C1</td>
</tr>
<tr>
<td>Cement (kg/m³)</td>
<td>16</td>
<td>24</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Class C fly ash (kg/m³)</td>
<td>184</td>
<td>177</td>
<td>386</td>
<td>380</td>
</tr>
<tr>
<td>Sand, SSD (kg/m³)</td>
<td>1702</td>
<td>1716</td>
<td>1337</td>
<td>1319</td>
</tr>
<tr>
<td>Fibrous residual (kg/m³)</td>
<td>0</td>
<td>0</td>
<td>42</td>
<td>82</td>
</tr>
<tr>
<td>Water (kg/m³)</td>
<td>283</td>
<td>265</td>
<td>297</td>
<td>268</td>
</tr>
<tr>
<td>W/Cm</td>
<td>1.41</td>
<td>1.31</td>
<td>0.71</td>
<td>0.65</td>
</tr>
<tr>
<td>Flow (mm)</td>
<td>255</td>
<td>255</td>
<td>225</td>
<td>265</td>
</tr>
<tr>
<td>Air content (%)</td>
<td>0.9</td>
<td>1.6</td>
<td>1.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>2180</td>
<td>2180</td>
<td>2100</td>
<td>2080</td>
</tr>
</tbody>
</table>
Pouring slurry into a 75 × 150 mm cylindrical mold for flow test

Center for By-Products Utilization
Measurement of flow diameters

Center for By-Products Utilization
Flowable slurry for measuring density and air content
Casting cylindrical specimens for compressive strength
ASTM D 6024 Ball-drop test
Ball-drop diameter on fly ash flowable slurry

Center for By-Products Utilization
Ball-Drop Diameter on Ash Slurry

- The ball-drop diameter on Mixtures FA-WR and FA-C1 reached about 80 mm in about one week and one one day, respectively.

- When new Mixtures FA-WR-2 and FA-C1-2 were made by reducing the W/Cm from about 0.6 to 0.5, the time to reach a ball-drop diameter of approximately 75 mm shortened to about 18 and 1.5 hours, respectively.
Ball-drop diameter on sand flowable slurry

![Graph showing the ball-drop diameter in millimeters (mm) as a function of age in days. The graph includes data points for Sd-Ref, Sd-Ref-2, Sd-WR, and Sd-C1.](image-url)
Ball-Drop Diameter on Sand Slurry

- Mixture Sd-Ref remained soft for over a week due to its relatively high W/Cm and low C/Cm.
- Mixture Sd-Ref-2 was produced with a lower W/Cm and higher C/Cm than Mixture Sd-Ref.
- Mixtures Sd-Ref-2, Sd-WR, and Sd-C1 set within two days.
Cylinder being tested in compression
Compressive Strength of CLSM

Unconfined compressive strength of CLSM (ASTM D 4832) should be [ACI-229 1999]:

- 0.35 to 0.7 MPa (50 to 100 psi) for backfills to allow for manual excavation
- ≤ 2.1 MPa (300 psi) to allow for excavation by using a backhoe
- 2.8 to 8.3 MPa (400 to 1200 psi) for pavement bases.
## Compressive Strength of Fly Ash Flowable Slurry (MPa)

<table>
<thead>
<tr>
<th>Age (days)</th>
<th>FA-Ref</th>
<th>FA-Ref-2</th>
<th>FA-WR</th>
<th>FA-WR-2</th>
<th>FA-C1</th>
<th>FA-C1-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.45</td>
<td>0.46</td>
<td>0.16</td>
<td>0.45</td>
<td>0.10</td>
<td>0.68</td>
</tr>
<tr>
<td>7</td>
<td>0.48</td>
<td>0.43</td>
<td>0.20</td>
<td>0.60</td>
<td>0.10</td>
<td>0.73</td>
</tr>
<tr>
<td>28</td>
<td>0.63</td>
<td>0.66</td>
<td>0.26</td>
<td>0.66</td>
<td>0.12</td>
<td>0.90</td>
</tr>
<tr>
<td>56</td>
<td>6.52</td>
<td>8.52</td>
<td>0.28</td>
<td>0.89</td>
<td>0.13</td>
<td>0.88</td>
</tr>
<tr>
<td>91</td>
<td>8.82</td>
<td>8.87</td>
<td>0.32</td>
<td>0.99</td>
<td>0.14</td>
<td>0.91</td>
</tr>
<tr>
<td>182</td>
<td>9.35</td>
<td>13.84</td>
<td>0.71</td>
<td>1.14</td>
<td>0.55</td>
<td>n. a.</td>
</tr>
</tbody>
</table>
# Compressive Strength of Sand Flowable Slurry (MPa)

<table>
<thead>
<tr>
<th>Age (days)</th>
<th>Sd-Ref</th>
<th>Sd-Ref-2</th>
<th>Sd-WR</th>
<th>Sd-C1</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.08</td>
<td>0.08</td>
<td>0.17</td>
<td>0.13</td>
</tr>
<tr>
<td>7</td>
<td>0.09</td>
<td>0.07</td>
<td>0.17</td>
<td>0.14</td>
</tr>
<tr>
<td>28</td>
<td>0.47</td>
<td>0.79</td>
<td>0.23</td>
<td>0.15</td>
</tr>
<tr>
<td>56</td>
<td>1.07</td>
<td>1.22</td>
<td>0.58</td>
<td>0.18</td>
</tr>
<tr>
<td>91</td>
<td>1.12</td>
<td>1.38</td>
<td>0.88</td>
<td>0.18</td>
</tr>
<tr>
<td>182</td>
<td>1.26</td>
<td>1.63</td>
<td>1.12</td>
<td>0.31</td>
</tr>
</tbody>
</table>
Sealing Test Specimen in Preparation for Hydraulic-Conductivity Test

Center for By-Products Utilization
Apparatus for hydraulic-conductivity test

Center for By-Products Utilization
Hydraulic Conductivity (Water Permeability)

The hydraulic conductivity of hardened flowable slurry was determined in accordance with ASTM D 5084 using falling head and constant tailwater elevation.
Hydraulic conductivity of fly ash flowable slurry
Hydraulic Conductivity of Ash Slurry

- Among the fly ash slurry mixtures, Mixtures FA-Ref and FA-Ref-2 made without fibrous residuals showed the lowest hydraulic conductivity because of their very high compressive strength.
Hydraulic Conductivity of Ash Slurry (cont’d)

• Among the fly ash slurry mixtures made with fibrous residuals, Mixture FA-C1-2 showed the lowest hydraulic conductivity ($2.2 \times 10^{-6}$ cm/sec at 91 days) in part due to its relatively high strength.

• Mixture FA-C1 was less permeable than Mixture FA-WR, although Mixture FA-C1 showed lower compressive strength than Mixture FA-WR.
Hydraulic Conductivity of Ash Slurry (cont’d)

• Similarly, Mixture FA-C1-2 was considerably less permeable than Mixture FA-WR, even though the compressive strength of both mixtures was comparable at 28 and 91 days.

• Thus, use of Residual C1 was helpful in reducing the hydraulic conductivity of fly ash slurry, compared with use of Residual WR.
## Hydraulic conductivity of sand flowable slurry ($10^{-6}$ cm/sec)

<table>
<thead>
<tr>
<th>Age (days)</th>
<th>Sd-Ref</th>
<th>Sd-Ref-2</th>
<th>Sd-WR</th>
<th>Sd-C1</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>12.8</td>
<td>16.7</td>
<td>13.5</td>
<td>8.7</td>
</tr>
<tr>
<td>91</td>
<td>10.1</td>
<td>12.1</td>
<td>6.2</td>
<td>6.4</td>
</tr>
</tbody>
</table>
Hydraulic conductivity of sand flowable slurry

Hydraulic conductivity (cm/s)

Age (days)

Sd-Ref
Sd-Ref-2
Sd-WR
Sd-C1

Hydraulic conductivity of sand flowable slurry
Hydraulic Conductivity of Sand Slurry

- In spite of lower strength at 28 and 91 days, Mixtures Sd-WR and Sd-C1 containing fibrous residuals were generally less permeable to water than Mixtures Sd-Ref and Sd-Ref-2 made without fibrous residuals.
Hydraulic Conductivity of Sand Slurry (cont’d)

• Among mixtures containing fibrous residuals, the lower-strength Mixture Sd-C1 showed either about the same or lower permeability than the higher-strength Mixture Sd-WR.

• Thus, use of fibrous residuals, especially C1, was helpful in reducing the hydraulic conductivity.
CONCLUSIONS

• Fibrous residuals improved workability of fly ash slurry. \(\rightarrow\) Easier (less time-consuming) to thoroughly mix the ingredients.

• Fibrous residuals prevented rapid setting of the fly ash slurry mixtures made with Class C fly ash and kept the fresh ash slurry mixtures workable while they were being placed.
CONCLUSIONS (cont’d)

• Fibrous residuals helped the fly ash and sand slurry mixtures to set at an early age and maintain a low long-term strength, allowing for future excavation.

• Use of fibrous residuals, especially C1, was helpful in reducing the hydraulic conductivity of sand flowable slurry.
Acknowledgement

- The UWM Center for By-Products Utilization was established in 1988 with a generous grant from the Dairyland Power Cooperative, LaCrosse, WI; Madison Gas and Electric Company, Madison, WI; National Minerals Corporation, St. Paul, MN; Northern States Power Company, Eau Claire, WI; We Energies, Milwaukee, WI; Wisconsin Power and Light Company, Madison, WI; and Wisconsin Public Service Corporation, Green Bay, WI. Their financial support and additional grant and support from Manitowoc Public Utilities, Manitowoc, WI, and gratefully acknowledged.
THANK YOU
for your interest

http://www.cbu.uwm.edu

ymchun@uwm.edu
tarun@uwm.edu
rudik@uwm.edu