Use of Wood Micro-Fibers to Increase Freezing and Thawing Durability of Concrete

by

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Micro-fibers from 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 (gravity/primary and biological/secondary).
- Usually, dewatered before disposal or beneficial use.
Paper Mill Wastewater Treatment Process

- Mill Wastewater
- Primary Clarifier
- Secondary Clarifier
- Dewatering
- Primary Residual
- Secondary Residual
- Recovered Water
- Clarified Water

Recovered Water
Dewatered Residual

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Pulp and Paper Mill Residual Solids in Concrete

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

• Because of cellulose fibers in the residual solids, the residual solids could become an economical source of fibers for use in concrete.
Reasons for Fiber Reinforcement of Concrete

• Inherently, concrete is a brittle material.
• By incorporating fibers into concrete, its toughness and tensile strength could be improved; and, also, shrinkage cracking could be reduced.
Properties of Micro-fibers

- **Steel**
- **Carbon**
- **Wood Cellulose**

<table>
<thead>
<tr>
<th>Property</th>
<th>Steel</th>
<th>Carbon</th>
<th>Wood Cellulose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect Ratio, L/D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modulus of Elasticity (GPa)</td>
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</tbody>
</table>
Pulp and Paper Mill Residual Solids in Concrete

• There have been very few investigations.
• Best performance of concrete seems to be achieved if the residual solids were collected prior to chemical conditioning and solidification.
As-received fibrous residual C1
As-received fibrous residual WR

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Characterization of the Residuals

Seven sources of residual solids from various types of mills were selected.
- Primary and/or combined (primary + secondary) residuals
- Virgin-fiber and recycled-fiber residuals

- Physical and chemical properties determined.
- Effects of dispersants on sludge to separate fibers established.
# Characteristics of Residuals

<table>
<thead>
<tr>
<th>Type of Residual</th>
<th>6 Primary, 1 Fiber reclaim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber Origin</td>
<td>5 Virgin, 1 Recycled, 1 Mixed</td>
</tr>
<tr>
<td>Moisture Content (%)*</td>
<td>153 (84-230)</td>
</tr>
<tr>
<td>Wood Fiber (%)*</td>
<td>57 (35-94)</td>
</tr>
<tr>
<td>LOI at 590°C (%)*</td>
<td>65.9 (43.6-99.6)</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.83 (1.56-2.17)</td>
</tr>
<tr>
<td>Avg. Fiber Length, $L_L$ (mm)</td>
<td>1.27 (0.85-1.68)</td>
</tr>
</tbody>
</table>

* % of oven-dry mass.
Strength and Durability of Concrete Containing Residual Fibers

Mixture Proportions

– Residual content of 0.65 to 1.5%.
– Initial and final setting times evaluated.
– Air-entraining admixture (AEA) was not used.
– HRWRA was used to adjust slump.
<table>
<thead>
<tr>
<th>Mixture</th>
<th>Ref1</th>
<th>C1</th>
<th>C2</th>
<th>WG</th>
<th>WV</th>
<th>Ref2</th>
<th>BR</th>
<th>I</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residuals (kg)</td>
<td>0</td>
<td>15.6</td>
<td>15.7</td>
<td>15.6</td>
<td>15.7</td>
<td>0</td>
<td>8.5</td>
<td>16.0</td>
<td>15.7</td>
</tr>
<tr>
<td>HRWRA (L)</td>
<td>0.8</td>
<td>1.8</td>
<td>3.0</td>
<td>2.2</td>
<td>3.4</td>
<td>0.8</td>
<td>1.5</td>
<td>3.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Cement (kg)</td>
<td>368</td>
<td>360</td>
<td>363</td>
<td>359</td>
<td>361</td>
<td>367</td>
<td>365</td>
<td>368</td>
<td>363</td>
</tr>
<tr>
<td>Sand (kg)</td>
<td>856</td>
<td>837</td>
<td>848</td>
<td>836</td>
<td>841</td>
<td>852</td>
<td>847</td>
<td>855</td>
<td>841</td>
</tr>
<tr>
<td>19-mm Coarse Aggregate (kg)</td>
<td>1050</td>
<td>1030</td>
<td>1030</td>
<td>1020</td>
<td>1030</td>
<td>1050</td>
<td>1040</td>
<td>1050</td>
<td>1030</td>
</tr>
<tr>
<td>W/Cm</td>
<td>0.43</td>
<td>0.41</td>
<td>0.43</td>
<td>0.45</td>
<td>0.44</td>
<td>0.43</td>
<td>0.41</td>
<td>0.42</td>
<td>0.44</td>
</tr>
<tr>
<td>Slump (mm)</td>
<td>115</td>
<td>90</td>
<td>150</td>
<td>180</td>
<td>125</td>
<td>75</td>
<td>125</td>
<td>90</td>
<td>75</td>
</tr>
<tr>
<td>Air Content (%)</td>
<td>1.6</td>
<td>2.8</td>
<td>1.6</td>
<td>1.8</td>
<td>1.7</td>
<td>1.9</td>
<td>2.3</td>
<td>1.3</td>
<td>1.8</td>
</tr>
<tr>
<td>Unit Wt. (kg/m³)</td>
<td>2430</td>
<td>2390</td>
<td>2420</td>
<td>2400</td>
<td>2410</td>
<td>2420</td>
<td>2410</td>
<td>2440</td>
<td>2410</td>
</tr>
</tbody>
</table>
Compressive strength of concrete (ASTM C 39)
Cylinder broken in compression
Compressive strength of concrete (ASTM C 39) (cont’d)

- Ref. 2
- BR
- I
- S

Age (days) vs. Compressive Strength (MPa)
Length change test using a comparator (ASTM C 157)
Length change of concrete due to curing in water and drying in air

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Resistance of Concrete to De-icing Chemicals (ASTM C 672)

![Graph showing resistance of concrete to de-icing chemicals over salt scaling cycle]
Change in Dynamic Modulus of Elasticity of Concrete Due to Freezing and Thawing (ASTM C 666 A)
Residual Flexural Strength (ASTM C 1339)

- Concrete containing residuals showed slightly improved residual-strength than concrete without residuals.
Chloride-ion penetration resistance test
Electrical Indication of Chloride Ion Penetrability Into Concrete (ASTM C 1202)

Mixture Name

Charge Passed (Coulombs)

Ref. 1  C1  C2  WG  WV  Ref. 2  BR  I  S

High
Moderate
Very Low
Negligible
Abrasion test
Mass loss of concrete due to abrasion

Mass Loss After Six Minutes of Abrasion (g)

- Ref. 1
- C1
- C2
- WG
- WV
- Ref. 2
- BR
- I
- S

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Construction Demonstration
CONCLUSIONS

When compared to a reference concrete containing no residuals, concrete containing residuals exhibited:

• Slightly lower compressive strength
• higher average residual-strength
• Equivalent drying-shrinkage
• Improved resistance to freezing and thawing
• Equivalent or lower chloride-ion penetration resistance and abrasion resistance.
Thank you very much for your interest.
Spaceship Earth – La Bella Terra

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Aabhar Tamaro, Afcharisto Poly, Arigatou Gozaimasu, Grazie Molte, Maraming Salamat, Merci Beaucoup, Muchas Gracias, Muito Obrigado, Dziekuje, Salamat, Shukriya, Spasibo, Thank you, Toda Raba.