USE OF RESIDUAL SOLIDS FROM PULP AND PAPER MILLS FOR ENHANCING STRENGTH AND DURABILITY OF READY-MIXED CONCRETE
-Year 2, Fourth Quarter

By Tarun R. Naik

Report No. CBU-2002-01
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Fourth quarterly technical report for Year 2 submitted to the US Department of Energy for the Project DE-FC07-00ID13867

Department of Civil Engineering and Mechanics
College of Engineering and Applied Science
THE UNIVERSITY OF WISCONSIN-MILWAUKEE
FEDERAL ASSISTANCE PROGRAM/PROJECT STATUS REPORT

1. Program/Project Identification No. DE-FC07-00ID13867

2. Program/Project Title Use of Residual Solids from Pulp and Paper Mills for Enhancing Strength and Durability of Ready-Mixed Concrete

3. Reporting Period 10/1/01 to 12/31/01

4. Name and Address

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5. Program/Project Start Date 1/1/00

6. Completion Date 12/31/02

7. Approach Changes

Based upon the work completed to date, some revisions to the research approach are desirable. New work-plan and budget need to be authorized.

8. Performance Variances, Accomplishments, or Problems

No problems have been encountered during this phase of the project. The Fourth Quarter’s activities for Year 2 (October 1, 2001 to December 31, 2001) of the US-DOE Project Agenda 2020, “Use Of Residual Solids from Pulp And Paper Mills for Enhancing Strength And Durability of Ready-Mixed Concrete,” are reported here. During this quarter, durability and long-term testing of concrete containing residual solids were conducted; average residual-strength and variability of residual solids were determined; and a preliminary specification for use of residual solids in concrete was developed. Tests were continued for the evaluation of length change (drying shrinkage), resistance to surface scaling from deicing chemicals, and resistance to freezing and thawing of concrete containing residual solids. Drying shrinkage of concrete containing residual solids was comparable to that of reference concrete. Compared to reference concrete, concrete containing residual solids showed higher resistance to surface scaling from deicing chemicals, as well as higher resistance to freezing and thawing cycling. Average residual-strength of concrete was determined. In general, concrete containing residual solid showed higher residual-strength than reference concrete. Variability of residual solids was also evaluated. Overall, there was minor variation in the characteristics of residual solids in terms of moisture content and specific gravity. However, there was a large variation in the moisture content between deliveries for one source of residuals. Based on the results of testing conducted for this project, a preliminary specification was developed for use of residual solids in concrete. The specification is based upon testing of a standard concrete mixture with approximately four-inch slump and a compressive strength at 28 days of 7000 psi. A total of seven sources of residual solids were tested in concrete.

9. Open Items

No open items remain from work scheduled to be completed for the quarter 10/1/01 – 12/31/01.

10. Status Assessment and Forecast

Testing of concrete mixtures made in earlier phases/activities of the project will be continued. Specifications on the use of residual solids in concrete will be revised as additional test data is collected. Commercial concrete producers participating in this project will be consulted on the planned manufacturing activities for 2002. Mixture proportions will be selected for manufacturing and refined as necessary with the producer.

11. Description of Attachments

The quarterly progress report presenting project results from October 1, 2001 to December 31, 2001 is attached. The yearly progress report (through Year 2) is also attached.

12. Signature of Recipient and Date

13. Signature of U.S. Department of Energy (DOE) Reviewing Representative and Date
Quarterly Progress Report

For: Use of Residual Solids from Pulp and Paper Mills for Enhancing Strength and Durability of Ready-Mixed Concrete

Covering Period: October 1, 2001 to December 31, 2001

Date of Report: January 29, 2002

Recipient: University of Wisconsin - Milwaukee
UWM Center for By-Products Utilization
College of Engineering and Applied Science

Award Number: DE-FC07-00ID13867

Subcontractors: None

Other Partners: Weyerhaeuser Company, NCASI, and Stora-Enso

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Project Team: David W. Robertson, Project Manager
U.S. DOE Idaho Operations Office
850 Energy Drive, MS 1220
Idaho Falls, ID 83401-1563

Project Objective:

This project is proposed to provide a practical solution to disposal problems for pulp and paper mill by-products and provide an economical source of fiber reinforcement for ready-mixed concrete production. The first year's project activities are directed toward optimizing mixture proportions and production technologies under controlled laboratory conditions. Fibrous residuals generated from pulp and paper mills will be used for the first year's activities. The second year's activities (Year 2) involve study of market acceptance as well as market barriers for the use of residual solids in the ready-mixed concrete. Economic impact will be studied and additional specialized tests will be conducted. The activities proposed for the third year (Year 3) will involve pilot-scale production at ready-mixed concrete manufacturing plants and cast-concrete products (bricks, blocks, and paving stones) with concrete mixtures containing pulp...
and paper mill by-products. A number of cost-effective concrete products could then be manufactured using pulp and paper mill residual solids. As a result, large amounts of such by-products that are currently being landfilled can be utilized in the manufacture of concrete products. Specifically, the goals of this project will be:

(1) Monitor new literature and research for specifications and other requirements for concrete with residual solids.

(2) Collect laboratory performance data for high-strength/high-performance/high-quality/high-durability concrete containing residual solids.

(3) Conduct tests for physical, chemical, and morphological properties of residual solids to ensure that the residual solids will have the desirable characteristics for the intended field application in various types of ready-mixed concrete production.

(4) Conduct a market study to understand market acceptance as well as market barriers for the use of residual solids in ready-mixed concrete. Evaluate economic impact.

(5) Conduct specialized long-term and durability laboratory tests on concrete containing residual solids.

(6) Conduct field performance evaluation for production of ready-mixed concrete with residual solids and construction demonstration.

(7) Provide practical production and construction information to potential users, producers, engineers, owners, paper industry officials, government officials, and others regarding ready-mixed concrete with residual solids. Prepare information on various options for use, mixture proportioning, and results of field demonstration projects. Conduct technology transfer workshops for products containing residual solids (for example, in conjunction with field demonstrations).

(8) Provide guidelines for mixture proportioning for production of ready-mixed concrete with residual solids for manufacturers.

(9) Produce draft specifications for residual solids use to guide pulp and paper mills, ready-mixed concrete producers, and other users in potential applications and to satisfy other requirements such as strength and durability.

(10) Work with selected pulp and paper mills to implement this new technology in their geographical area.

Background:

Each year (1996) over 3.7 million tons of pulp and paper mill primary effluent treatment solids (a.k.a. "sludge") containing useful fibers and natural chemicals are generated in the USA. About two-thirds of these solids are disposed in landfills and incinerators. Assuming an average disposal cost of $30/ton, this translates into at least a $70 million/year cost to the industry. Some mills report disposal costs up to $100/ton. One quarter of these primary residual solids is beneficially applied to land as a soil conditioner and another one quarter of it is burned to
extract energy or reduce its volume for landfill disposal. However, these options are not always feasible at many mills for various reasons, including limited or rotating availability of farm lands or air emissions concerns. Disposal in landfills for such residuals remains the primary option for many pulp and paper mills, even though it can involve potential long-term environmental risks. At the present time, 45% of such residuals are landfilled. Industrialists as well as environmentalists now agree that this is a lost opportunity for resource recovery. Therefore, it has become essential to find value-added constructive use options for these residuals. The residuals included in this proposal are primary treatment solids, and de-ink and recycling solids from paper recycling. No current funding for this or other closely related project exists.

The proposed research program is to develop a new type of ready-mixed concrete using fibrous residuals from pulp and paper mill. Varying lengths of fibers available from such residuals will help lead to a reduction in the plastic and drying shrinkage cracks in the concrete. Based upon research data available, decreased cracking of concrete exposed to weather improves its durability and its life span. Earlier work by T. Naik in the states of Wisconsin and Washington has also shown that judicious use of fibers leads to decreased cracking in concrete which increases the compressive strength, tensile strength, flexural strength, flexural-fatigue strength, and ductility (i.e., total energy required to failure or modulus of toughness) of the concrete. Many studies reported by T. Naik and others have shown that high-strength/high-performance/high-quality/high-durability concrete can be made only with selective use of concrete mixture proportions, including use of chemical admixtures, mineral additives, and fibers. Such concrete can be expected to last 100 years or more, rather than the normally accepted life span of 25 to 35 years. This proposed project is expected to at least double the life span of concrete structures through the addition of residual solids from pulp and paper mills. Initial work completed by T. Naik, using four different sources of residual solids, has shown that compressive strength can be increased up to 25 to 50 percent at the age of 7 to 28 days, with a corresponding increase in tensile strength. This is due to the fibers and chemicals available from pulp and paper mill residuals, which improve the microstructure of the ready-mixed concrete at the interface of the cement hydration products and the sand grain and/or coarse aggregate (stone) surface. Such new ready-mixed concrete with cellulose fibers will be used for increasing the life span of our nation’s infrastructure, especially highways, roadways, and airport pavements because these structures are subjected to extreme forces of nature, constant assault by vehicles, and degradation by application of de-icing salts.

Status:

During this quarter, durability and long-term tests were conducted; average residual-strength and variability of residual solids were determined; and preliminary specification for use of residual solids in concrete was developed.

Durability and Long-Term Tests

Tests were continued for the evaluation of length change, resistance to salt scaling, and resistance to freezing and thawing of concrete containing residual solids. Length change of concrete containing residual solids was comparable to that of reference concrete. Compared to reference concrete, concrete containing residual solid generally showed higher resistance to salt scaling and freezing and thawing.
Fig. 1 -- Length Change of Concrete Due to Drying Shrinkage
Fig. 2 -- Salt Scaling of Concrete
Fig. 3 --Change in Dynamic Modulus of Elasticity of Concrete Due to Freezing and Thawing
Average Residual-Strength

Average residual-strength of concrete was determined according to ASTM C 1399 at age of 112 days. In general, concrete containing residual solids showed higher residual-strength than reference concrete. Overall, residual-strength index of concrete was about 1% of peak strength (modulus of rupture).

Table 1 -- Average Residual-Strength of Concrete

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ref. 1</th>
<th>C1</th>
<th>C2</th>
<th>WG</th>
<th>WV</th>
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<tbody>
<tr>
<td>MOR (psi)</td>
<td>887</td>
<td>943</td>
<td>962</td>
<td>868</td>
<td>876</td>
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<tr>
<td>RS (psi)</td>
<td>3.2</td>
<td>6.6</td>
<td>11.6</td>
<td>4.9</td>
<td>11.4</td>
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<tr>
<td>RSI (%)</td>
<td>0.4</td>
<td>0.7</td>
<td>1.2</td>
<td>0.6</td>
<td>1.3</td>
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</table>

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ref. 2</th>
<th>BR</th>
<th>I</th>
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<tr>
<td>MOR (psi)</td>
<td>947</td>
<td>887</td>
<td>964</td>
<td>953</td>
</tr>
<tr>
<td>RS (psi)</td>
<td>9.6</td>
<td>8.0</td>
<td>14.4</td>
<td>14.3</td>
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<td>RSI (%)</td>
<td>1.0</td>
<td>0.9</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

* RSI = RS / MOR

Variability of Residual Solids

Overall, there was minor variation in the characteristics of residual solids in terms of moisture content and specific gravity. However, a large increase in moisture content of WV residual solids was noted.

Table 2 -- Variation of Moisture Content and Specific Gravity of Residual Solids

<table>
<thead>
<tr>
<th>Sample</th>
<th>Date Sample Received</th>
<th>Moisture Content</th>
<th>Specific Gravity</th>
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<tr>
<td></td>
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<td>2</td>
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<tr>
<td>C1</td>
<td>5/17/00</td>
<td>11/1/01</td>
<td>185</td>
</tr>
<tr>
<td>C2</td>
<td>5/19/00</td>
<td>11/1/01</td>
<td>220</td>
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<tr>
<td>I</td>
<td>5/23/00</td>
<td>N.A.</td>
<td>95</td>
</tr>
<tr>
<td>S</td>
<td>5/16/00</td>
<td>10/23/01</td>
<td>84</td>
</tr>
<tr>
<td>WG</td>
<td>5/16/00</td>
<td>11/6/01</td>
<td>116</td>
</tr>
<tr>
<td>WV</td>
<td>5/17/00</td>
<td>12/14/01</td>
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<tr>
<td>BR</td>
<td>3/1/01</td>
<td>11/14/01</td>
<td>230</td>
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</table>

Specification for Concrete Containing Residual Solids

Based on test results collected so far, a preliminary specification is developed for use of residual solids in concrete. This is based on test results on concrete containing about 600 lb of cement, 1400 lb of sand, and 1700 lb of angular coarse aggregate per cubic yard, with about
four-inch slump and 7000 psi expected 28-day compressive strength. A total of seven sources of both primary and recycled paper mill residual solids were included in concrete. ADVA™ Flow was used as a high-range water reducer (HRWR); Rheobuild 3000FC and/or other brands of HRWR should give similar performance.

1. Residual solids
   For easier and uniform distribution of residual solids in concrete, excessive de-watering of residual solids needs to be avoided.
   In case residual solids have to be stored for an extended period of time, they should be stored in a refrigerated room to prevent potential biodegradation of cellulose fibers.

2. Characterization of Residual Solids
   Moisture content, specific gravity, and loss on ignition (LOI) at 590°C of residual solids need to be determined for mixture proportioning purpose. As-received sample, not oven-dry sample, should be used for determining specific gravity.
   If LOI at 590°C result is not available, it can be estimated as:
   \[
   \text{LOI} \% = (\frac{73}{\text{specific gravity}} + 200)
   \]

3. Mixture Proportioning
   With the objective of including residual solids in concrete and producing comparable slump, unit weight, and compressive strength with reference (plain without residual solids) concrete, the following adjustments to reference concrete mixture proportion must be considered.
   a. Reduce water content
      Reduce the amount of water by:
      \[
      \frac{WR}{100 + MR} \times \left( \frac{100}{GR + MR} + WH \times MH \right)
      \]
      where:
      \(WR\) = As-received weight of residual solid (lb)
      \(MR\) = Moisture content of as-received residual solid (%)
      \(GR\) = Specific gravity of residual solid
      \(WH\) = Weight of HRWR (lb)
      \(MH\) = Moisture content of HRWR (%)
      This ensures that the unit weight of residual solid-containing concrete will be comparable to that of the reference concrete.
   b. Determine amount of HRWR to be added
      Amount of HRWR to be added for achieving comparable slump with that of reference concrete is roughly about 7.5 fl oz/100 lb of cement for one lb of residual solids (based on LOI at 590°C)/100 lb of cement. Manufacturer’s recommended maximum HRWR content of about 10 fl oz/100 lb of cement corresponds to about 1.33 lb of residual solid (based on LOI at 590°C)/100 lb of cement, which converts to as-received residual solid content of 0.5 to 1.0% by weight of concrete.

4. Mixing
   a. Premixing of residual solids with water
      For uniform distribution of residual solid in concrete, residual solid need to be dispersed uniformly in water prior to its introduction into the concrete batch. This can be done by mechanically stirring residual solid in water using, for example, a high-shear mixer. For a rather stiff and dry source of residual solid, mixing in hot water can be considered for better dispersion.
   b. Batching sequence
      Follow generally established batching sequence used for plain concrete or the
sequence specified in ASTM C 192. Introduce high-range water reducer (HRWR) and residual solids separately, as residual solids may absorb HRWR if they are premixed together.

5. Placing

Conventional method of placing concrete works satisfactory with residual solid-containing concrete.

**Plans for Next Quarter:**

Testing of concrete mixtures made in earlier phases/activities of the project will be continued. Specifications on the use of residual solids in concrete will be revised as additional test data is collected.

Commercial concrete producers participating in this project will be consulted on the planned manufacturing activities. Mixture proportions will be selected for manufacturing and refined as necessary with input from the producer.
**Budget Data** (as of December 31, 2001):

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<th>Phase / Budget Period</th>
<th>Approved Spending Plan</th>
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<td>Totals</td>
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Program/Project Title: Use of Residual Solids from Pulp and Paper Mills for Enhancing Strength and Durability of Ready-Mixed Concrete

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<th>Description</th>
<th>Planned Completion Date</th>
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<td>March 2000</td>
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<td>Task 4</td>
<td>Reporting for Year 1.</td>
<td>December 2000</td>
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<td>Task 7</td>
<td>Durability and Long-term Testing of Manufactured Concrete.</td>
<td>December 2001</td>
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<td>Testing for long-term durability continues under Task 13</td>
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<td>Variability evaluation will be continued during Year 3, Task 13</td>
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<td>Task 16</td>
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<td>December 2002</td>
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