USE OF RESIDUAL SOLIDS FROM PULP AND PAPER MILLS FOR ENHANCING STRENGTH AND DURABILITY OF READY-MIXED CONCRETE
-Year 3, First Quarter

By Tarun R. Naik

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First quarterly technical report for Year 3 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
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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
01/01/02 to 03/31/02

4. Name and Address
Professor Tarun R. Naik, Ph.D., P.E.
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Milwaukee, WI 53201

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.

No problems have been encountered during this phase of the project.

The First Quarter’s activities for Year 3 (January 1, 2002 to March 31, 2002) 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, long-term tests on the concrete made in Year 2 were continued. Modeling of compressive strength of concrete was conducted as a preparation for manufacturing concrete with residual solids at a commercial plant. Splitting tensile and flexural strengths and response to air-entraining admixtures were compared for reference (plain) concrete and residual concrete.

9. Open Items
No open items remain from work scheduled to be completed for the quarter 01/01/02 – 03/31/02.

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.

A commercial plant will be selected and concrete with residual solids will be manufactured at the plant. Tests will be conducted for fresh and hardened concrete properties. Mixtures with best overall performance will be selected for construction demonstration.

11. Description of Attachments
The quarterly progress report presenting project results from January 1, 2002 to March 31, 2002 is 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: January 1, 2002 to March 31, 2002

Date of Report: April 30, 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 <http://www.uwm.edu/Dept/CBU> 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, long-term tests on the concrete made in Year 2 were continued. Modeling of compressive strength of concrete was conducted as a preparation for manufacturing concrete with residual solids at a commercial ready-mixed concrete plant. Splitting tensile and flexural strengths and response to air-entraining admixture were compared for reference (plain) concrete and residual concrete.

A total of 32 concrete mixtures were manufactured in the laboratory to determine the combined effect of residual solid content and HRWA content. For each of seven sources of residual solids, four concrete mixtures were made for a two-level factorial experiment for compressive strength. Two variables were used at two levels each: (1) residual solid content (based on LOI at 590°C) at 0 and 1 lb/100 lb of cement and (2) HRWR (High-Range Water Reducer) content at 0 and 7.5 fl. oz/100 lb of cement. Slump was maintained at about three inches. Results of the experiments showed that the residual concrete specification developed in Year 2 would be
useful for producing a residual concrete whose compressive strength is equivalent to that of a reference (plain) concrete (Figure 1).

![Figure 1 – Compressive Strength of Concrete as Influenced by Residual and HRWR Contents](image)

At the age of 28 days and at a comparable level of compressive strength, a residual concrete showed about 4% and 15%, respectively, higher splitting tensile and flexural strengths than that for the concrete without residual solids (Figure 2).

![Figure 2 – Splitting Tensile and Flexural Strengths of Residual Concrete and Reference Concrete](image)
When an air-entraining admixture (AEA; Daravair® 1400) was used at a fixed dosage rate of 2.7 fl. oz/100 lb of cement, concrete with residual solids showed, on average, air content of 4.2%, unit weight of 147 lb/ft$^3$, and 28-day compressive strength of 5840 psi. Corresponding values for a reference concrete without residual solids with the same amount of AEA were 6.6%, 143 lb/ft$^3$, and 5150 psi. Manufacturer’s recommended maximum dosage rate for the AEA is 3 fl. oz/100 lb of cement.

**Plans for the Next Quarter:**

A commercial ready-mixed concrete plant will be selected. Concrete with residual solids will be manufactured at the plant. Tests will be conducted for fresh and hardened concrete properties. Mixtures with best overall performance will be selected for construction demonstration.

Construction demonstration location will be selected.
**Budget Data (as of March 31, 2002):**

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<th>Phase / Budget Period</th>
<th>Approved Spending Plan</th>
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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

**Program/Project ID No.:**
DE-FC07-00ID13867

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<th>ID No.</th>
<th>Description</th>
<th>Planned Completion Date</th>
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