Center for
By-Products
Utilization

USE OF RESIDUAL SOLIDS FROM PULP AND PAPER MILLS FOR ENHANCING STRENGTH AND DURABILITY OF READY-MIXED CONCRETE

By Tarun R. Naik

Report No. CBU-2000-10.3
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Fourth quarterly technical report 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
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  10/1/00 to 12/31/00

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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 may be desirable.

8. Performance Variances, Accomplishments, or Problems

No problems have been encountered during this phase of the project. Some modifications in the project milestone plan may be desirable.

The primary task completed for the fourth quarter was continued development and testing of concrete mixture proportions. Three series of concrete mixtures containing residual solids were made and tested during the fourth quarter consisting of a total of 31 mixtures. Based on the concrete mixing and testing during the fourth quarter, the following conclusions were reached: (1) Based on the properties of concrete containing residuals, none of the seven sources of residuals contain materials that harm the performance of concrete. (2) Use of residual solids increases water demand and decreases workability of concrete. This is most probably due to the presence of clay (for some sources of residual) and/or cellulose fibers clumped in residuals. (3) Even when more water was used for concrete with residuals, it was not possible to maintain comparable slump with the reference concrete. Also, due to the use of more water, the strength of concrete decreased accordingly. (4) With the use of HRWR, it was possible to keep the slump of concrete with residuals at the same level as reference concrete without adding more water. However, the concrete strength still decreased at about the same overall rate as when more water was used without HRWR. (5) When the amount of mixing water was calibrated so that the volume of mixing water and residuals was kept constant, strength of concrete was also held constant. Slump was kept at equivalent level with the help of HRWR for these mixtures. This is considered to be a breakthrough achievement to date for this project.

9. Open Items

No open items remain from work scheduled to be completed for the quarter 10/1/00 – 12/31/00.

10. Status Assessment and Forecast

The focus of the next quarter’s work will be on the continuation of evaluation of mechanical properties and testing of durabilities properties of concrete mixtures. The properties to be evaluated include compressive strength, splitting tensile strength, flexural strength, dimensional change, chloride ion penetration, abrasion resistance, etc. Other activities planned for the next quarter includes gathering information required for the market study and economic impact study. The data will include cost information from concrete producers and pulp and paper mills for establishing cost of these new type of concrete mixtures.

11. Description of Attachments

A copy of the annual technical report presenting complete project results from January 1, 2000 to December 31, 2000.

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, 2000 to December 31, 2000

Date of Report: December 31, 2000

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 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) involves 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:**

Three series of concrete mixtures (Series C to E) containing residual solids were made and tested during the fourth quarter. Initially (Series A), all seven sources of residual solids were incorporated in concrete. After this initial series of mixtures, five out of seven sources of residuals were further evaluated in Series B. Compression, splitting tensile, and flexural strength
of concrete was determined for the first two series of mixtures. Results of Series A and B mixtures were reported in the third quarter report of Year 1.

Four sources of residuals (C1, C2, WG, and WV) were investigated in Series C to E concrete mixtures. These mixtures were evaluated for compressive strength. When calculating water to cementitious materials ratio (W/Cm), all the water contained in residual solids was included in the amount of water added to the concrete batch. Water contained in HRWR was also taken into account. Residual solids content of concrete for Series C, D, and E was based on as-received weight of residual solids. This was done mainly for the convenience of mixture proportioning. As-received weight includes weight of fibers, clay (if any), and water. These materials in the residual have bearing on the properties of concrete, especially water demand and thus workability/fluidity/slump and strength of concrete.

In addition to the Series C-E mixtures completed for the fourth quarter, two more trial series of mixtures were made. One of them was conducted between Series B and Series C mixtures. From this trial series, it was established that HRWR by itself does not govern the strength of concrete. What controls the strength is the amount of water or W/Cm. From this observation, it was decided to vary the level of residual content and HRWR content for the design of experiment carried out in Series C.

The second trial series, conducted between Series C and D, evaluated cement paste, mortar, concrete with a 3/8” maximum size aggregate, and concrete with ¾” maximum size aggregate. This second trial series was to determine if higher residual fiber content in cement-based materials would produce improved ductile behavior. Although ductile behavior of paste, mortar, or concrete has not yet been evaluated, it was realized that as the volume of cement paste in concrete (mortar or paste) increased, more residual could be incorporated. Also, it was found that for paste and mortar mixing, water should be introduced into concrete mixer before any other material.

Investigation on the use of cement paste and mortar containing paper mill residual as insulating concrete could be of value especially for the WG and P residual sources which have a high fiber content. This evaluation would require some revisions to the research approach currently planned and approved by US-DOE.

The purpose of Series C mixtures was to determine the effects of residuals and HRWR contents on the amount of mixing water required to produce a workable concrete and, therefore, on the strength of concrete. Levels of residual content were 0.05% (low) and 0.15% (high) based on LOI by weight of concrete. Residual content of 0.15% based on LOI corresponded to about as-received residual content of 0.46% (for WV) to 0.81% (for C1) based on weight. Levels of HRWR content were 1 (low) and 3 (high) expressed as multiple of 200 ml/100 kg of cement (3 liquid oz./100 lb of cement). For each source of residuals, four (2 level x 2 level) mixtures of concrete were produced, for a total of 16 mixtures. Slump was kept in the range of 100 ± 50 mm (4 ± 2in.). For most mixtures, the slump was between 100 ± 25 mm (4 ± 1 in.). Amount of mixing water was adjusted in order to keep the slump within this range while varying the contents of residual and HRWR. This change in the volume of mixing water was the key factor
that affected W/Cm, unit weight and, ultimately, strength of concrete. For each mixture of concrete, only compressive strength was determined at this stage by testing two cylinders at the each age of 3, 7, and 28 days.

For Series D, concrete was produced with same W/Cm expecting to get comparable strength. Residual solids content was 0, 0.35, and 0.65% based on as-received weight by weight of concrete. Amount of HRWR was calculated using the information derived from Series C mixtures. A total of nine mixtures were evaluated in Series D. For most of the concrete mixtures, slump was measured to be about 60 to 200 mm (2.25 to 8 in.). For WV mixture with residual content of 0.65% (WV-65), the slump was only 25 mm (1 in.). The critical parameter W/Cm ratio, varied very narrowly between 0.41 to 0.43. The unit weight of concrete decreased as residual content increased. Compressive strength was determined at 3, 7, and 28 days.

A total of nine mixtures were evaluated as part of Series E. For Series E mixtures, the amount of water was much more carefully calibrated with the objective of not displacing cement, sand, or coarse aggregate with the introduction of residual solids. For a given amount of residual solids, volume of residual solids and of water contained in them was calculated using their specific gravity, and water corresponding to the volume that was removed from the original amount of mixing water. Also, amount of water corresponding to the water contained in HRWR was also measured and accounted for. This ensured that the sum of volume of mixing water and residual solids would remain constant. In this way, it was expected that the amount of cement, sand, and coarse aggregate in a unit volume of concrete batch would not be reduced by the introduction of bulky residual solids. Thus unit weight of concrete would not be much reduced and more comparable compressive strength between concrete of different residual content should result. Average W/Cm was calculated to be was about 0.44 for series E, which was 0.02 higher than that for Series D (0.42). W/Cm slightly decreased for Series E as the residual content increased. For most mixtures, slump was 90 to 150 mm (3.5 to 6 in.). For WV concrete mixture, with 0.65% as-received residual content (WV-65), a little more water than calculated value had to be added in order to produce a slump of 50 mm (2 in).

Based on the concrete mixing and testing conducted during the fourth quarter of Year 1, the following conclusion were reached:

1. Based on the properties of concrete containing residuals, none of the seven sources of residuals contain any harmful materials for the performance of concrete.
2. The use of residual solids increases water demand and decreases workability of concrete. This is most probably due to the presence of clay (for some sources of residual) and/or cellulose fibers clumped in residuals.
3. Even when more water was used for concrete with residuals, it was not possible to maintain comparable slump with the reference concrete. Also, due to the use of more water, the strength of concrete decreased accordingly.
4. With the use of HRWR, it was possible to keep the slump of concrete with residuals at the same level as reference concrete without adding more water. However, the concrete strength still decreased at about the same overall rate as when more water was used.
without HRWR. This was attributed to the displacement of solid material per unit volume of concrete due to the introduction of residuals.

5. When the amount of mixing water was calibrated so that the volume of mixing water and residuals was kept constant, strength of concrete was also held constant. Slump was kept at equivalent level with the help of HRWR.

6. With up to 0.65% as-received sludge content by weight, 28-day compressive strength of about 48 MPa (7000 psi) was achieved regardless of residual content. This is a breakthrough achievement of Year 1.

7. At the start of Year 1, based upon past research, it was expected that the optimum level of primary residual solids from pulp mills would be about 0.2 to 0.4% (by weight of concrete) based upon the weight of as-received residuals (depending upon the type of residuals). However, Year 1 data established that up to 0.65% as-received residuals by weight (for any type of residuals) can be used without any adverse effect on strength. However, the upper limit of the amount of residuals has not yet been tested. Further testing of the upper limit may require some revisions to the research approach. Additional work is planned to be conducted if revisions to planned activities can be implemented.

Plans for Next Quarter:

The focus of the next quarter’s work will be on the continued evaluation of mechanical properties and durability properties of concrete mixtures. The properties to be evaluated includes compressive strength, splitting tensile strength, flexural strength, dimensional change, chloride ion penetration, abrasion resistance, etc. Other activities planned for the next quarter includes gathering information required for the market study and economic impact study. The data will include cost information from concrete producers and pulp and paper mills for establishing cost of this new type of concrete.

Future Work

Work for Year 2 of the project will consist of the following activities: Activity 5: Market Study, including the economics of residuals transport from source to user as part of the feasibility assessment; Activity 6: Economic Impact Study; Activity 7: Durability and Long-term Testing of Manufactured Concrete; Activity 8: Evaluation of Effects of Variability of Residual Solids (including consideration of any material that could be considered to have toxic or safety issues); Activity 9: Specifications for use in Ready-Mixed Concrete; and Activity 10: Initial Technology Transfer Activities & Reports
### Budget Data (as of December 31, 2000):

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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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