Center for By-Products Utilization

RECENT RECYCLING RESEARCH ACTIVITIES AT UWM-CBU

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Report No. CBU-2003-27
REP-521
August 2003

For presentation and publication at the Tenth International Conference on "Ashes from Power Generation", Warsaw, Poland, October 2003.

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PROJECT 1 - COAL COMBUSTION BY-PRODUCTS: CHARACTERIZATION AND USE OPTIONS

Introduction

An AFBC system installed at a boiler was composed of a circulating fluidized bed boiler. The boiler was designed to operate in a combination with a number of fuels including coal, petroleum coke, natural gas, etc. In the mid 1990s, the unit was firing a combination of coal and petroleum coke to generate energy.

It has been established that physical and chemical properties of the AFBC by-products could vary from plant to plant depending upon type and source of fuel, type of sorbent used, operating condition of the plant, and other factors. Therefore, it is important to determine physical and chemical properties, and morphology, of the AFBC CCP materials for determining the most appropriate use options.

In this the first phase of activities, the project was mainly directed toward determination of physical, chemical, mineralogical, and microscopical properties of the fly ash and bottom ash. The primary objective of this project was to determine potential applications of these materials.

Use Options

The combustion by-products (fly ash and bottom ash) analyzed have considerable potential for numerous applications. However, the performance of these by-products needs to be established for individual applications.

The following are some of the high-volume applications of the by-product that need further investigations. It is anticipated that these applications could consume most of the by-products produced.

Low And Medium Strength Concretes

The fly ash can be used as a partial replacement of both cement and fine aggregate, whereas the bottom ash can be used as a replacement of fine aggregate. In order to determine the effects of inclusion of the by-product on concrete strength and durability properties, "proof-of-concept" lab study should be conducted.

Flowable Fill Materials

Large amounts of both the fly ash as well as the bottom ash could be utilized in the manufacture of flowable fill material. This is a low-strength material whose strength can vary from 10 to 1200 psi at the age of 28 days. This material can be used for foundations, bridge abutments, buildings, retaining walls, utility trench as backfills, as embankments, grouts, and other similar applications.

Such material can be manufactured with large amounts of the fly ash and bottom ash generated, low amounts of cement, and high water-to-cementitious ratios to produce flowable materials. A study was conducted in order to produce mixture proportioning relationships for various recycling applications of this material.

Bricks, Blocks, and Paving Stones

These by-products have a great potential for applications in numerous masonry products such as bricks, blocks, and paving stones. Additionally, the fly ash can be utilized as a replacement of clay in manufacture of clay bricks. However, in order to meet the ASTM requirements and other qualities that are needed for masonry products, testing work should be undertaken. The results of such testing would be useful in developing specifications of the masonry products containing these by-products.

Autoclaved Cellular Concrete (ACC)

This material is composed of cement, powder silica sand, limestone, aluminum powder, and water. These by-products can be used as a replacement of sand. This requires establishment of performance of ACC made with this by-product.

PROJECT 2 - DEVELOPMENT OF CONTROLLED LOW STRENGTH MATERIALS ("MANUFACTURED SOIL") UTILIZING CCPs FROM AFBC BOILER

Introduction

This project was conducted for the development of Controlled Low Strength Materials (CLSM), a.k.a. manufactured soil, mixtures utilizing locally available coal combustion by-products. Two types of ash material were used for this project, North Silo ash and South Silo ash. This report summarizes the results of the laboratory activities of the project. Due to the cementitious nature of the South Silo ash material, it was decided that cement be not used for the CLSM mixture. The South Silo ash was described by power plant official to produce heat (exothermic reaction) after water was added.

Mixture Test Results

Three mixtures were selected for submission to the Wisconsin DNR for a CLSM project permit application. The following is a summary of these results.

Three bench-scale mixtures were selected for further testing as part of this project. None of the mixtures utilized cement. The three mixtures developed were:

(1) 100% South Silo ash, Mix MPU-2.
(2) 50% South Silo ash and 50% North Silo ash, Mix MPU-7.
(3) 75% North Silo ash and 25% South Silo ash, Mix MPU-8b or 8c.

Density of the fresh CLSM increased as the amount of South Silo Ash increased.
Compressive strength of the CLSM mixtures ranged from 105 psi for the 75% North Silo ash + 25% South Silo ash mixture to 650 psi for the 100% South Silo ash mixture. If the CLSM is expected to be excavated in the future, the lower strength CLSM should be utilized due to the increased cost of excavating a mixture with a compressive strength above 100 psi at the 28-day age. The South Silo ash material was found to be expansive. This expansion was readily apparent for the 100% South Silo ash mixture. The expansive properties of the CLSM may be

desirable in certain applications, for example, filling abandoned tunnels or tanks where assurance of complete and tight fill may be desirable.

Permeability of the CLSM was very low, approximately 10 to 100 times lower than that of compacted sand. The length change values after 7-day age show some expansion but not to the extent of the material at ages of less than 7-day age (as measured by settlement values of the cylinders still in their molds).

Oxide analysis of the hardened CLSM indicated that the oxide composition of the material was approximately the same as what would be obtained by blending the two sources of ashes. Minerals present in the CLSM materials were different than the original minerals depending upon the ash type. The CLSM containing 100% South Silo ash contained nearly 60% gypsum while nearly 70% of the material for the 75% North + 25% South Silo mixture was amorphous (glass phase).

PROJECT 3 - FLOWABLE SLURRY CONTAINING FOUNDRY SANDS

This work was carried out to evaluate the use of foundry sand on physical properties of flowable slurry. Two different flowable slurry mixtures were proportioned for strength levels in the range of 50 to 100 psi at 28 days using two different sources of foundry sand and ASTM Class F fly ash. Flowable slurry mixtures containing fly ash from two different sources, without any foundry sand, were used as reference mixtures for this investigation. Fly ash slurry has a long, successful history of use as a construction material. For each reference mixture, additional mixtures incorporating clean and used foundry sands as a replacement of fly ash were also proportioned. The foundry content was varied from 30 to 85% for both the reference mixtures.

The ingredients of the slurry mixtures, which included cement, fly ash, clean foundry sand, and used foundry sand, were tested for their physical and chemical properties. The results show that foundry sands are useful for manufacture of flowable slurry materials. These flowable mixtures made with and without foundry sand were evaluated for bleeding, depth of nail penetration, settlement, shrinkage, condition of set, and other rheological properties. In general, bleedwater increased with an increase in water or foundry sand content, or both, in the mixtures tested. The settlement decreased with the decrease in water content of the slurry. All test specimens did not show any signs of shrinkage cracks. The depth of nail penetration decreased with decreasing water content or increasing age. Compressive strength of the test mixtures was found to vary between 40 to 90 psi at the age of 28 days. The overall results showed that excavatable flowable slurry with desirable physical properties can be manufactured using foundry sand as a replacement of fly ash up to 85 percent.

PROJECT 4 - USE OF GLASS CULLET AS AGGREGATES IN FLOWABLE CONCRETE WITH FLY ASH

The emphasis of this project was to develop a flowable concrete utilizing post-consumer glass aggregate and fly ash. The flowable concrete developed in this project also met the ACI Committee 229 specifications for controlled low-strength materials (CLSM). Approximately 170 thousand tons of glass by-products are generated each year in Wisconsin alone. Problems associated with glass recycling are breakage and mixing of colors. Two types of flowable concrete were developed as a part of this project. Flowable concrete consisting of fly ash, cement, and water, Type I, and a flowable concrete consisting of sand, cement, and water, Type II (used where fly ash is not available or if manufacturers do not have facilities for handling fly ash). For the Type I flowable concrete, a total of six different flowable mixtures were developed. A control mixture containing no glass and five other mixtures were proportioned with glass as a replacement of fly ash in the range of 20 to 80 percent by weight. For Type II flowable concrete, a total of three different mixtures were developed. A control mixture and two mixtures proportioned with 30 and 75 percent replacement of sand with glass. All mixture components such as fly ash, glass, cement, and sand were characterized for their chemical and physical properties. Appropriate ASTM standards were followed for all testing. Rheological properties of the mixtures were determined. Hardened slurry properties tested included compressive strength, permeability, and density. The compressive strength of all mixtures were considered to be acceptable for future excavatability. Unit weight of the mixtures increased with increased percentages of glass. Decreasing the amount of fly ash and increasing the glass content lead to increased bleeding and segregation at high replacement levels of 60% and 80%. This was attributed to decreased cohesiveness due to the decreased fly ash contents and subsequently increased flow of the mixture. Permeability of the flowable concrete also increased as the percentage of glass was increased in mixtures. Generally, glass cullet was found to be an acceptable aggregate source for use in a flowable concrete.

PROJECT 5 - LOW-COST, HIGH-PERFORMANCE MATERIALS (CONCRETE AND CAST-CONCRETE PRODUCTS) USING CLASS F FLY ASH

This project was proposed to provide a practical solution to disposal problems for Illinois coal combustion products (CCPs). The entire project work was organized in three phases, each phase lasting one year. Phase I work was directed toward optimizing mixture proportions for ready-mixed concrete and masonry products containing Illinois coal ash through lab investigation during the year 1994-1995. In this Phase a number of candidate mixtures for concrete, bricks, blocks, and paving stones were established based on data collected regarding strength and durability performance. In Phase II (1996-1997), mixtures selected from Phase I were field manufactured in Illinois and evaluated to establish optimum concrete mixture proportions containing Class F fly ash. Phase III, 1999-2000, emphasized the utilization of clean-coal ash and blends of clean-coal ash with Class F fly ash from Illinois in production of concrete and cast-concrete products.

In phase III, three non-air entrained, three non-air entrained (HPC) with a high-range water reducing admixture, and three air entrained concrete mixtures were manufactured at the facilities of the United Ready-Mix, Inc., Peoria, IL. One mixture of each type of concrete was Control Mixture without fly ash and the remaining mixtures contained clean-coal ash up to a maximum of 35% by weight based upon total cementitious materials and 5% by weight Class F fly ash based upon total aggregates content, as a partial replacement of aggregates. Concrete mixtures were evaluated for strength and durability properties. Specimens were tested for compressive strength, splitting tensile strength, flexural strength, abrasion, and drying shrinkage.

Fifteen cast-concrete product mixtures consisting of five 8-in. hollow-core block mixtures, five 2-in. solid paving stone mixtures, and five brick mixtures were manufactured at the facilities of Crumb-Colton Block Company, Rockford, IL. These masonry product mixtures contained up to a maximum of 45% clean-coal fly ash based upon total cementitious materials, and 8% by weight of Class F fly ash, based upon total aggregates content as a partial replacement of aggregates. The block, paving stone, and brick mixtures were tested and evaluated for compressive strength, absorption, density, freezing and thawing resistance, and abrasion as required by the applicable ASTM standards.

Based upon the results of the project, both clean-coal ash and Class F fly ash, or a combination of the two, may be successfully used in applications for both concrete and cast-concrete products.

PROJECT 6 - IMPLEMENTATION OF TECHNOLOGY FOR CONTROLLED LOW-STRENGTH MATERIALS USING ClASS F FLY ASH W/CRUSHED LIMESTONE SAND

Over 90% of 5.5 million tons per year of coal ash produced from burning Illinois-coal is currently disposed in landfills. The focus of this project was to develop a high-volume Illinois-coal ash content controlled low-strength material (CLSM) (a.k.a. flowable slurry). The CLSM slurry manufactured as a part of this project consisted of very low amounts of cement, high-volumes of Illinois-coal ash, and water to produce flowable slurry for many construction applications. Use of CLSM as a construction material would consume large amounts of Illinois-coal ash providing economic as well as ecological benefits. Illinois Department of Transportation (IDOT) and other currently available construction specifications from Illinois were used for manufacturing CLSM in Rockford and Peoria at ready-mixed concrete/CLSM manufacturing plants.

Two series of CLSM were batched in the laboratory. Series 1 CLSM mixtures were composed of a fine crushed sand, Illinois-coal ash, and cement. Series 2 was composed of a combination of typical concrete sand, Illinois-coal ash, and cement. Mixtures for both series varied the coal ash and sand content from 0% Illinois-coal ash, and 100% sand to 100% coal ash with 0% sand. Laboratory mixtures were evaluated for fresh CLSM properties as well as compressive strength and water permeability. The laboratory mixtures were then used as the basis for mixture proportions used for field manufacturing. Series 1 field mixtures were manufactured at the facilities of Meyer Material Co. and Rockford Sand and Gravel, Inc., Rockford, IL; while Series

2 field mixtures were manufactured at the facilities of the United Ready-Mix, Inc., Peoria, IL. The CLSM test mixtures manufactured generated the necessary experimental and production data to optimize CLSM mixture proportions for commercial production. Two construction demonstration/technology transfer workshops were held in Illinois. One field demonstration was held in Rockford, IL, in cooperation with the Rockford Blacktop Construction Co., and a second demonstration and technology transfer workshop was held in Peoria, IL with the cooperation from the United Ready-Mix, Inc. and City of Peoria Department of Public Works.

PROJECT 7 - DEVELOPMENT AND DEMONSTRATION OF HIGH-CARBON CCPS AND FGD BY-PRODUCTS IN PERMEABLE ROADWAY BASE CONSTRUCTION

This investigation was conducted to develop and demonstrate permeable base course materials using coal combustion products (CCPs) for highways, roadways, and airfield pavements. Three types of CCPs, two high-carbon, high-sulfate flue-gas desulfurization (FGD) by-products and a variable-carbon fly ash, were evaluated for no-fines or low-fines concrete as a permeable base material.

A total of 56 mixtures were proportioned and manufactured in the laboratory in this project. Mixture proportions for the base course materials were developed using a two-step experimental optimization process. The first step involved developing mixture proportions for permeable base course materials containing no CCPs. A total of 26 mixtures were produced in the first step. The optimum mixtures developed from the first step of the experimental process were used as candidate mixture proportions for the second step of the optimization process. The second step of the mixture optimization included various combinations of the three selected CCPs for developing mixtures for base course materials. Specimens from each mixture were made using roller-compacted concrete (RCC) technology in accordance with ASTM C 1435. Three different series of ten base course mixtures were developed and tested based on the structure of the base course: dense-graded, intermediate-graded, and open-graded. Each mixture was evaluated for both strength and durability properties. The strength properties evaluated consisted of compressive strength (ASTM C 39), flexural strength (ASTM C 78), and splitting tensile strength (ASTM C 496). Durability properties consisted of drying shrinkage (ASTM C 157), resistance to sulfate exposure (modified ASTM C 1012), and resistance to rapid freezing and thawing (modified ASTM C 666).

Based on the mixture proportions established in the laboratory, four prototype open-graded base course mixtures containing one source of CCP were manufactured at a commercial ready-mixed concrete plant in Green Bay, Wisconsin.

A full-scale base course mixture was produced for a construction demonstration, which was held in conjunction with a technology transfer educational workshop conducted in Green Bay, Wisconsin, in September 2002. The base course concrete mixture was open-graded to maximize drainage capability. The mixture was made by replacing approximately 50 % of the cement with one of the sources of CCPs evaluated. Desirable compressive and flexural strength were achieved from the mixture used for the demonstration.

PROJECT 8 - DEVELOPMENT AND DEMONSTRATION OF POROUS BASE COURSE MATERIALS FOR PAVEMENTS USING CLASS F FLY ASH

This project was developed as a technology transfer program to develop a porous, low-strength concrete that uses large amounts of non-specification ash generated from the combustion of coal from Illinois. The Illinois-coal combustion products used for this project had a very high carbon content, over 30%. Typically, high-carbon ash have little use in construction materials; however, previous project work conducted by the UWM Center for By-Products Utilization showed the feasibility of using this type of ash in porous base construction. A properly designed and constructed porous base eliminates pumping, faulting, and cracking in the pavement, thus increasing the service life of roadways, highways, and air field pavements.

Porous concrete mixtures were first manufactured and tested in the UWM-CBU laboratory. These laboratory mixtures varied the amount of ash from 0% to approximately 50%. These mixtures were evaluated for fresh porous concrete properties as well as compressive strength, splitting tensile strength, flexural strength, drying shrinkage, sulfate resistance, and resistance to freezing and thawing. Hardened concrete properties were evaluated up to the age of 91 days. The laboratory mixtures were then used as the basis for mixture proportions used for field manufacturing. Pilot-scale field mixtures were manufactured at the facilities of the United Ready-Mix, Inc., Peoria, IL. The porous concrete field mixtures generated the desirable experimental and production data to determine acceptable levels of coal ash in porous base concrete mixtures for commercial production.

To disseminate the results of this project to others in Illinois, a construction demonstration/technology transfer workshop was held in Peoria with cooperation from the United Ready-Mix, Inc. and the City of Peoria, Department of Public Works. The workshop consisted of lectures presenting technical results obtained for this project as well as a construction demonstration on the placement of porous base course concrete for a section of a street in Peoria. The porous concrete mixture used for the demonstration used the highest amount of Illinois-coal ash tested for the project, over 50% by weight of the total cementitious materials. Results of the project indicate that high-carbon Illinois-coal ash may successfully be used in porous base course applications.

PROJECT 9 - SELF-COMPACTING CONCRETE

Self-compacting concrete (SCC) is one of the important recent developments in the field of concrete technology. Self–compacting concrete is highly flowable but segration-resisting concrete with ability to fill every corner of a formwork and get compacted by its self-weight ensuring homogeneity. Development of self-compacting concrete is a very desirable achievement in the construction industry for overcoming problems associated with the cast-inplace concrete. Quality of the construction using self-compacting concrete is not affected by the skill of workers, and shape and amount of reinforcing bar arrangement of a structure. SCC has made possible to cast heavily reinforced thin sections of architectural structures. Due to high-fluidity and resisting power of segregation of self-compacting concrete, it can be pumped longer distances. Self-compacting concrete extends the possibility of use of various mineral by-products in its manufacturing due to requirement of high-volume of fine material. All types of structural construction including precasting are possible with SCC. The use of SCC not only shortens the construction period but also helps assume quality control and durability of concrete. The covers of reinforcing bars are of improved quality that makes more corrosion resistance construction. This is a non-vibrating concrete that allows faster placement and much less finishing time leading to improved productivity. Use of this concrete in construction industry reduces a number of environmental impacts such as noise pollution for workers and neighbors of the construction site; reduced energy consumption during construction; etc. Currently, self-compacting concrete is being rapidly adopted in many countries due to its numerous inherent advantages over traditionally vibrated concrete. However, there is a need for conducting development work for the measurement and standardization of the methods for the evaluation of the self-compacting characteristics of SCC.

PROJECT 10 - CLSM CONTAINING MIXTURES OF COAL ASH AND A NEW POZZOLANIC MATERIAL

Significant amount of ash is generated from burning wood with supplementary fuels such as coal, oil, natural gas, and coke by pulp and paper mills and wood-products manufacturers. Thus the ash generated from such facilities is a mixture of wood ash and ashes generated from such supplemental fuels. In this investigation, such wood ash was referred to as a combined-fuel ash (CFA).

This investigation was carried out to develop Controlled Low-Strength Materials (CLSM) mixtures using various sources of CFAs. Three different series of CLSM mixtures were manufactured using five sources of CFAs. Each series of CLSM mixtures was designed for a different long-term compressive strength, <0.7 MPa (<100 psi), 0.7 to 3.4 MPa (100 to 500 psi), and 3.4 to 8.3 MPa (500 to 1,200 psi). All CLSM mixtures were tested for flow, bleedwater, settlement, shrinkage and cracking, setting characteristics, density, compressive strength, and permeability. The results revealed that CLSM, meeting ACI 229 requirements, can be manufactured using substantial amounts of CFAs.

PROJECT 11 - CONCRETE BRICK AND BLOCK MANUFACTURING USING WOOD ASH GENERATED FROM WISCONSIN PULP AND PAPER INDUSTRY

The major objective of this project was technology demonstration and transfer of technology for use of wood ash in brick and block manufacturing to enhance economic development for Wisconsin pulp and paper mills. The objective was to introduce concrete products manufacturers to the use of wood ash as a cost effective source of pozzolanic material for the production of cast concrete products. This project formed a mutually beneficial economic tie between the pulp and paper industry and concrete products manufacturers.

A total of 18 different concrete mixtures for bricks and blocks were manufactured at a plant in Racine, Wisconsin. Nine mixtures were for concrete blocks and an additional nine mixtures for concrete bricks. The type and amount of wood ash was varied for each mixture. A maximum of 35% wood ash was used in these concrete bricks and blocks. Four block and four brick mixtures were also used in combination of wood ash and coal ash with up to a 50% reduction in the cement normally used in bricks and blocks by this manufacturing plant. Brick or block specimens cast from each mixture were evaluated for compressive strength, water absorption, and resistance to freezing and thawing cycles. Results were compared with standard ASTM requirements. Test results indicate that concrete block mixtures can successfully incorporate up to 35% wood ash. Concrete block mixtures that contained a combination of wood ash and coal ash with up to 50% cement reduction also met strength requirements. Concrete brick mixtures containing wood ash and a combination of wood ash with coal ash also met requirements when moderate strength and durability properties are specified.

PROJECT 12 - ENHANCING STRENGTH AND DURABILITY OF CONCRETE WITH PULP AND PAPER MILL RESIDUALS

Abstract

Fibrous residuals generated from pulp and paper mills were incorporated in concrete. In general, at comparable compressive strength, concrete containing the residuals was equivalent to plain concrete in average flexural-residual-strength in accordance with ASTM C 1399, length change (drying shrinkage), chloride-ion penetration resistance, and abrasion resistance. On the other hand, the residuals concrete showed generally much higher other durability properties than the plain concrete.

Project Objective

This project was proposed to provide a practical solution to disposal problems of 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 were directed toward optimizing mixture proportions and production technologies under controlled laboratory conditions. Fibrous residuals generated from pulp and paper mills were used for the first year's activities. The second year's activities (Year 2) involved study of market acceptance as well as market barriers for the use of residual solids in the ready-mixed concrete. Economic impact was studied and additional specialized tests were conducted. The activities for the third year (Year 3) involved 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. As a result, large amounts of such by-products that are currently being landfilled can be utilized in the manufacture of concrete products.

Conclusions

(1) Without the use of HRWRA, fibrous residuals from pulp and paper mills either reduce slump or increase water demand of concrete.

(2) With proper dosage of HRWRA, slump and compressive strength of concrete containing the residuals can be managed as desired. In general, dosage of HRWRA was proportional to the amount of wood fibers in concrete. Time of setting increased as the dosage of HRWRA increased. Residuals themselves did not affect the strength development of concrete.

(3) In general, at somewhat lower compressive strength, concrete containing the residuals showed higher average residual-strength, equivalent length change (drying shrinkage), and equivalent or lower chloride-ion penetration resistance and abrasion resistance when compared with reference concrete made without residuals.

(4) On the other hand, the residuals concrete showed, in general, much higher other durability properties.

(5) Field construction demonstrated the feasibility of ready-mixed concrete containing residual solids.