Center for By-Products Utilization

RECENT ADVANCES IN RECYCLING CLEAN-COAL ASH

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Report No. CBU-2004-09
REP-554
May 2004

For presentation and publication at Eighth International Gypsum and Fly Ash Conference, Toronto, Canada, June 2004.

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DEVELOPMENT OF CONTROLLED LOW STRENGTH MATERIALS ("MANUFACTURED DIRT") UTILIZING CLEAN-COAL ASH [1]

This project was for the development of mixtures of Controlled Low Strength Material (CLSM), a.k.a. manufactured dirt, utilizing the MPU power station coal combustion by-products (ash) from an FBC boiler. Two types of ash material were used for this project, MPU North Silo ash and MPU South Silo ash. The report presents results of the laboratory activities of the project. Due to the cementitious nature of the South Silo ash material, cement was not used when the CLSM mixture utilized the South Silo ash. The South Silo ash produced heat (exothermic reaction) after water was added.

CHARACTERIZATION AND APPLICATION OF CLASS F FLY ASH AND CLEAN-COAL ASH FOR CEMENT-BASED MATERIALS [2]

The major objective of this project was to develop technology for high-volume applications of high-sulfur coal combustion by-products generated by using both conventional and clean-coal technologies. A clean-coal ash is defined as the ash derived from SOx and NOx control technologies, and FBC and AFBC boilers. High-sulfur coal ashes, particularly clean-coal ashes are underutilized. This project was primarily directed toward developing concrete products incorporating large amounts of Class F and clean-coal ashes generated from combustion of high-sulfur coals. Fifteen coal ash samples were obtained from eight different sources burning high-sulfur coals to represent a spectrum of these coal ashes. These ashes were characterized for their physical, chemical, mineralogical, and microstructural properties. Based on these properties, two sources of both conventional (Class F) and clean-coal ashes were selected for further investigation. Two additional ash samples were prepared by blending these selected conventional and clean-coal ashes. Using these six different ash samples, nineteen concrete mixtures were proportioned for initial testing and evaluation. The results showed that structural-grade concrete could be manufactured using large amounts of conventional or clean-coal ashes, as well as the blended ashes.

Based on the results obtained from the initial testing, twenty-seven additional concrete mixtures were proportioned. Strength and durability testing of the final concrete mixtures revealed that structural-grade concrete could be manufactured having cement replaced with high-sulfur coal ashes (Class F and clean-coal ashes) and coal ash blends (Class F plus clean-coal ash blends) up to 60 percent. On the basis of results obtained in this investigation, several mixtures for the pilot-scale manufacturing of concrete were recommended.

USE OF CLASS F FLY ASH AND CLEAN-COAL ASH BLENDS FOR CAST CONCRETE PRODUCTS [3]

High-sulfur coal ash, particularly that obtained from clean-coal technology, are not utilized in cast-concrete masonry products (bricks, blocks, and paving stones) industry. This project was directed toward developing cast (masonry) concrete products incorporating large amounts of ashes generated from combustion of high-sulfur coals generated from both conventional and clean-coal technologies. Fifteen high-sulfur coal ash samples were obtained from eight different sources and tested for their physical, chemical, mineralogical, and microstructural properties. Based on these properties, two sources of both conventional (Class F) and clean-coal ashes were selected for further investigation. Two additional ash samples were prepared by blending these selected conventional and clean-coal ashes. Using these six different ash samples, eleven masonry mixtures were proportioned for initial testing and evaluation.

From results obtained in the initial phase, twenty-one additional masonry mixtures were proportioned. Strength and durability testing of the final mixtures revealed that masonry products could be manufactured with cement replacement up to 60 percent by high-sulfur coal ashes (Class F and clean-coal ashes) and coal ash blends (Class F plus clean-coal ash blends). Based on results obtained in this investigation, several mixtures were recommended for a pilot scale manufacturing of cast concrete products.

HIGH-STRENGTH HVFA CONCRETE CONTAINING CLEAN-COAL ASH [4]

This project was carried out to establish high-volume use technologies for manufacture of cement-based products using ashes generated from combustion of high-sulfur coals. The entire project was completed in two phases (Phase I and Phase II). Phase I was reported earlier [2].

Phase II investigation involved field-testing and evaluation of few selected mixtures established in Phase I. These mixtures were composed of non-air entrained concretes incorporating conventional fly ash for structural applications and air entrained concrete mixtures for use in normal concrete construction. The results revealed that non-air entrained ready-mixed concrete can be manufactured with up to 60% fly ash content for structural applications and air entrained concrete for up to 30% fly ash content for normal concrete construction.

DESIGN AND TESTING CLSM UTILIZING CLEAN COAL ASH [5]

The major objective of this project was to develop mixture proportions for Controlled Low Strength Material (CLSM) using clean-coal ash obtained from AFBC (Atmospheric Fluidized Bed Combustion) boiler. The specific ashes utilized for this project were: (1) circulating fluidized bed boiler fly ash and bottom ash; and, (2) stoker-type boiler fly ash and bottom ash. These two coal ash samples were characterized for physical and chemical properties, and water-leaching tests on the CLSM slurry made from them. Additional initial CLSM mixtures were also developed by blending these two ashes.

Tests conducted on the final three selected CLSM mixtures included compressive strength, bleeding, setting and hardening, settlement, length change of hardened CLSM, water permeability, mineralogy, and chemical water leach testing. Results show that acceptable CLSM material can be developed by blending the fluidized bed boiler ash with the stoker boiler ash. Recommendations for a pilot-scale manufacturing and application of the three CLSM mixtures were made based upon the lab test results.

USE OF CLEAN-COAL ASH AS SETTING TIME REGULATOR IN PORTLAND CEMENT [6]

Traditionally about 3 to 5% gypsum is inter-ground with portland cement clinker as setting time regulator for portland cement production. In this paper a source of clean-coal ash (CCA) was used to replace gypsum as a setting time regulator and mineral additive in CCA cements. Up to 80% of CCA was blended with ground portland cement clinker. The resulting blended cements were evaluated for time of setting (ASTM C191), soundness (ASTM C151), compressive strength (ASTM C109), and sulfate resistance (ASTM C 1012). Test results indicate that the time of setting of the blended cements increased with CCA content up to 40%, then decreased with higher CCA content. All the CCA cements with CCA were "sound" regarding the autoclave expansion test. The early strength (one day) of the CCA cements was decreased. However, from the age of seven days and above the compressive strengths of the CCA cements were equivalent to or higher than gypsum-regulated cement with up to 60% CCA. CCA cements were less vulnerable to sulfate attack than the gypsum-regulated cement.

LOW-COST, HIGH-PERFORMANCE MATERIALS USING ILLINOIS COAL COMBUSTION BY-PRODUCTS [7]

This project was proposed to provide a practical solution to disposal challenges associated with high-sulfur 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 ponded-Illinois-coal ash through lab investigation during the year 1994-1995. In Phase I, a number of candidate mixtures for concrete, bricks, blocks, and paving stones were established based on strength and durability performance data. In Phase II (1996-1997), mixtures selected from Phase I were field manufactured and evaluated to establish optimum concrete mixture proportions containing ponded-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 in production of concrete and cast-concrete products.

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 a control mixture without fly ash and the remaining mixtures contained fly ash up to a maximum of 35% of clean-coal ash based upon total cementitious materials and 5% by weight ponded-Class F fly ash as a partial replacement of aggregates. Concrete mixtures were evaluated for strength and durability related 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 ponded-Class F fly ash as a partial replacement of aggregates. Blocks, paving stones, and bricks 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 ponded-Class F fly ash can be successfully used in applications for both concrete and cast-concrete products.

CLEAN-COAL ASH AS A POTENTIAL SOURCE FOR DPC (DEFINED-PERFORMANCE CONCRETE) [8]

The purpose of this project was to conduct physical, chemical, mineralogical, and microstructural tests for determining properties of three sources of typical MPU clean-coal ashes (Combined MPU #5 and #7 Bottom Ash, MPU #8 Bottom Ash, and MPU #8 Fly Ash) to evaluate their potential options for beneficial reuse. The three ash sources were selected based upon their diverse character (such as color, texture, type of collection system/process, etc.). These three ash sources were specifically identified for characterization before their possible use in a new type of concrete called DPC (Defined-Performance Concrete). The primary objective of this project was to recommend alternatives to the normal practice of landfilling by evaluating potential reuse/recycle applications for these materials, especially in cement-based, durable, construction materials.

Evaluation was started with lab-scale production and testing of the MPU clean-ash use in the above-mentioned applications. Cost/benefit analysis and marketing studies were planned; and a long-term evaluation program for these products were started. This included the development of clean-coal ash specifications for high-potential, high-value, applications such as DPC (Defined-Performance Concrete).

USE OF SUPERPLASTICIZERS IN THE PRODUCTION OF HVFA CONCRETE CONTAINING CLEAN-COAL ASH AND PONDED-CLASS F FLY ASH [9]

This paper presents results of laboratory and field experimental programs carried out to investigate the use of superplasticizers in making HVFA and HPC concrete containing clean-coal ash and ponded-Class F fly ash. In Phase 1, nine concrete mixtures with HRWRA were made in the laboratory, consisting of one Control Mixture without ash, four mixtures with ponded-Class F fly ash, two mixtures with clean-coal ash, and the remaining two mixtures with blends of ponded-Class F fly ash and clean-coal ash. Test results indicated that concrete mixtures incorporating up to 50% ponded-Class F fly ash and up to 45 % clean-coal ash exhibited the required performance needed for structural-grade concrete. Mixtures with blends of 17 % ponded-Class F fly ash and up to 44 % clean-coal ash also met specified strengths for general concrete construction.

In Phase 2, four concrete mixtures containing HRWRA were made in the field at a ready-mixed concrete plant. The first concrete mixture was proportioned without fly ash to attain the 28-day compressive strength of 28 MPa. Three remaining concrete mixtures were proportioned with ponded-Class F fly ash up to 60 % of the total cementitious materials. Test results indicated that HVFA concrete mixtures, with HRWRA, achieved strengths and shrinkage comparable to Control Mixture. Concrete mixtures made with fly ash showed higher abrasion resistance than Control Mixture.

In Phase 3, three concrete mixtures containing HRWRA were made. The first concrete mixture was proportioned without fly ash to attain the 28-day compressive strength of 21 MPa. The second and the third concrete mixtures were proportioned with clean-coal fly ash up to 45% of the total cementitious materials. The third concrete mixture also contained 6% by mass of ponded (i.e., wet-collected), coarse Class F fly ash as a replacement for fine aggregates. Test results indicated that HVFA concrete made with clean-coal ash and ponded-Class F fly ash, with HRWRA, achieved comparable or better strength and durability properties than concrete made without the ash.

DEVELOPMENT AND DEMONSTRATION OF HIGH-CARBON CCPs AND FGD BY-PRODUCTS IN PERMEABLE ROADWAY BASE CONSTRUCTION [10]

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. This report summarizes the work completed for this two-year project.

A total of 56 mixtures were proportioned and manufactured in the laboratory in this research. 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 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.

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 mixture was open-graded to maximize drainage capability. The base course mixture was made by replacing approximately 50 % of the cement with one of the sources of CCP evaluated for this project. Adequate compressive and flexural strength were achieved from the mixture used for the demonstration.

USE OF FGD MATERIAL AND PONDED CLASS F CCPs IN READY-MIXED CONCRETE [11]

This paper presents the results of experimental investigations carried out to study the effects of FGD material and ponded-Class F CCPs (coarse Class F ash) on the properties of non-air-entrained and air-entrained concrete. Ponded-ash was a mixture of fly ash and bottom ash or boiler slag. Concrete was made and tested in laboratory as well as at a ready-mixed concrete plant. A total of nine concrete mixtures were produced: three non-air-entrained concrete mixtures, three non-air-entrained concrete mixtures with HRWRA, and three air-entrained concrete mixtures. Percentage of FGD material varied from 22 to 45 % of the total cementitious (cement and FGD material) materials in non-air-entrained concrete and 17 to 27 % in the air-entrained concrete. All concrete mixtures also contained ponded, coarse Class F ash, as a replacement of up to 6 % of aggregates. Control mixture of non-air-entrained concrete and non-air-entrained concrete with HRWRA were proportioned to attain 28-day compressive strength of 35 MPa. Control mixture of air-entrained concrete was proportioned to achieve compressive strength of 28 MPa at 28 days. Tests were performed for fresh concrete properties, and also for compressive strength, splitting tensile strength, flexural strength, and abrasion resistance. For air-entrained concrete mixtures, salt-scaling test was also conducted.
Based on the tests results it was concluded that: (1) non-air-entrained concrete mixtures can successfully incorporate up to 22 % FGD material and a blend of 34 % FGD material and 6 % ponded, coarse Class F ash; (2) FGD material up to 45 % and 6 % of ponded, coarse Class F ash can also be used in non-air-entrained concrete mixtures using HRWRA for general concrete construction; and, (3) air-entrained concrete mixtures incorporating up to 17 % FGD material and blends of 27 % FGD material and 5% ponded, coarse Class F ash can also be used for general concrete construction.

ACKNOWLEDGMENTS

The Center was established by a generous grant from the Dairyland Power Cooperative, La Crosse, WI; Madison Gas and Electric Company, Madison, WI; National Minerals Corporation, St. Paul, MN; Northern States Power Company, Eau Claire, WI; We Energies, Milwaukee, WI; Wisconsin Power and Light Company, Madison, WI; and Wisconsin Public Service Corporation, Green Bay, WI. Their support, and the support of Manitowoc Public Utilities, is gratefully acknowledged.

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