Center for By-Products Utilization

Tests of Wood Ash as a Potential Source for Construction Materials

By Tarun R. Naik

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Submitted to John Piotrowski
Packaging Corporation of America
Tomahawk, WI

Department of Civil Engineering and Mechanics
College of Engineering and Applied Science
THE UNIVERSITY OF WISCONSIN - MILWAUKEE

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Executive Summary

TITLE: Tests of Wood Ash as a Potential Source for Construction Materials

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BACKGROUND/PURPOSE: To conduct physical, chemical, mineralogical, and microstructural tests for determining properties of typical PCA's (Packaging Corporation of America) wood ashes (fly ash, precipitator ash, and bottom ash) for evaluating their potential options for beneficial reuse. These three ashes were selected based upon their diverse character (such as color, texture, and type of collection system/process etc.) in consultation with Mr. John Piotrowski of PCA, Tomahawk, WI.

OBJECTIVE: 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 construction materials.

CONCLUSIONS: PCA's wood ashes have considerable potential for many applications. However, the performance of these ashes needs to be established for individual applications. The following are some of the high-volume applications that would require further evaluation. These applications would consume all of the wood ashes produced at Tomahawk, WI. Flowable Materials have up to 1200 psi compressive strength, have flowing mud-type of consistency and fluidity, contain very little portland cement and a lot of water, and consist mostly of ash or similar materials. It is believed that concrete Bricks, Blocks, and Paving Stones could also be made with the wood ashes tested. Additionally the fly ash and precipitator ash should be useful for replacement of clay in clay bricks manufacturing. The test data collected also indicate that these wood ashes can be used as a partial replacement of aggregates and/or cement in Medium-Strength Concrete. It is also concluded that there is a potential for high-value use of the fly ash and precipitator ash in manufacturing Blended Cements. Soil stabilization or site remediation is another significant potential use of the ashes. For example, for log-yard paving (Roller Compacted Concrete Pavement) these wood ashes can function as a soil stabilizing or strengthening medium as well as significantly improving the performance of log-yards and reducing cost of handling logs and minimizing waste of logs.

RECOMMENDATIONS: Further evaluation is recommended, starting with lab-scale production and testing of wood ash use in the above applications. Cost/benefit analysis and marketing studies should be undertaken; and a long-term evaluation program for these

products should be started. This includes the development of wood ash specifications for high-potential, high-value, applications.

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Tests of Three Wood Combustion Products

INTRODUCTION

The scope of this project is to determine physical, chemical, mineralogical, and microscopical properties of the Packaging Corporation of America's (PCA's) wood combustion products. The primary objective of this project is to recommend alternatives to the normal practice of landfilling by recommending potential reuse/recycling applications of these materials. Three different types of wood combustion products were used in this project: fly ash, precipitator ash, and bottom ash.

It has been established that properties of wood combustion products (i.e. different types of wood ashes) can vary greatly from mill to mill depending upon the type and source of fuel, how the ash is collected, design and operation of the boiler, etc. Therefore, it is important to determine physical, chemical, and morphological properties of the wood ash for determining it's appropriate use options.

The following background information on the three ash materials was obtained from the Packaging Corporation of America, Tomahawk, WI.

Source	Boiler #7	Boiler #8	Boiler #10
Make of Boiler	B&W	B&W	CE
Type of Boiler	Spreader Stoker	Cyclone Single Firing	Spreader Stoker
Age of Boiler	43 yrs.	42 yrs.	21 yrs.
Type of Fuel	Bark, saw dust, and coal	coal	Bark, saw dust, and coal
Maximum Size of Wood Fuel	Hogged	N/A	Hogged
Amount of Fuel Used per year Per Year	12,600 coal 18,000 wood waste	30,000 coal	27,000 coal 110,000 wood waste
Burning Temperature, Deg.F	1300		1400
Type of Energy	Steam	Steam	Steam
Amount of Energy	340 dpy @ 70 k#/hr	345 dpy @ 150k#/hr	345 dpy @ 180k#/hr
Wet or Dry Ash Collection	Dry - Fly Wet - Bottom	Dry - Fly Wet - Slag	Dry - Fly Wet - Bottom
Amount of Bottom Ash	*	*	*
Amount of Fly Ash	**	**	**

(1) Coal and wood waste usage will increase in 1999 due to suspension of TDF use

(2) Flue gases from all three boilers discharge to common header then to precipitation. Fly ash per boiler is not segregated but combined. Fly ash is mixed with some water (for dust control) in an ash mixer prior to discharge.

(3) #7 and #10 bottom ash is quenched & drawn off by bottom conveyor.

(4) #8 slag is quenched & beneficially reused for road base - not included in above totals (~3000yd^3/yr)

(*) Combined total of bottom ash for all three boilers (#7,8, and 10) is 1,100 cu. yd. per month

(**) Combined total for fly ash for all three boilers (#7,8, and 10) is 3,200 cu. yd. per month

EXPERIMENTAL PROGRAM

A test program was designed to measure physical, chemical, mineralogical, and microscopical properties of the wood ashes from PCA boilers. Wood combustion products received from PCA were in the form of fly ash, precipitator ash, and bottom ash from Tomahawk, WI. In order to measure properties of these products, the following experiments were carried out.

PHYSICAL PROPERTIES

As-Received Moisture Content

As-received moisture content (MC) of the three wood ashes was determined in accordance with the ASTM Test Designation C 311. Table 1 provides the test results. The results show that the bottom ash had very high (68.8%) MC, precipitator ash and fly ash had a mid-range MC (29.5% and 23.7%, respectively). Due to high MC, there are some significant negative attributes of these wood ashes: (1) moisture/water content leads to cost of shipping water along with the wood ash to the potential user of the wood ash. This, of course, increases the cost to the user in obtaining the wood ash for beneficial reuse. (2) If the moisture content is not within control, then the variation leads to quality control problems for the user. (3) If the user is planning to use the wood ash in cement-based materials, then the water content becomes a critical parameter for manufacturing cement-based product because water content in cement-based materials must be controlled in a narrow range to control the quality of such products. (4) Wetting it with or soaking it in water destroys any cementitious ability of the wood ash. (5) A typical manufacturer of cement-based materials is equipped very well to handle dry or relatively dry materials. Therefore, wet or variable moisture content wood ash would make it harder for PCA to market these wood ashes for reuse/recycle purposes to such manufacturers.

Particle Size Analysis

All wood ash samples were first oven-dried at 210°F ± 10°F and were then tested for gradation using standard sieve sizes (1" through #100), as reported in Table 2, in accordance with ASTM Test Designation C 136. All wood ash samples were also tested in accordance with ASTM Test Designation C117 to determine the amount of material finer than No. 200 sieve by washing as reported in Table 3. Precipitator ash and fly ash samples were further tested for materials passing No. 325 sieve by washing under pressure in accordance with ASTM Test Designation C 430. Results are reported in Table 4. The size distributions of fine particles (passing #100 sieve) of the precipitator ash and fly ash were analyzed in accordance with ASTM C

422 (hydrometer analysis). The complete size distribution of the three wood ashes are shown in Fig. 1 to Fig. 3

Table 2 particle size analysis data show that the bottom ash generally had coarse materials in it and only 14% passed through the No. 100 sieve. Furthermore, bottom ash had only about 8% of the total materials passing No. 200 sieves when washed with water (Table 3). These test data show that bottom wood ash may be acceptable as a substitute for sand replacement in ready-mixed concrete and/or as both coarse and fine aggregates replacements in dry-cast concrete products such as bricks, blocks, and paving stones because of its generally coarse gradation. Furthermore, it will probably not be fine enough; i.e., it may be too coarse, as-produced as a cement replacement in concrete making.

Table 3 data show that PCA wood ash and precipitator ash had considerable amount of material passing No. 200 sieve (74% and 53%, respectively). The very fine material passing the No. 325 sieve was also quite a bit, about 70% on average for the two samples tested, Table 4. This indicates that this material is suitable for CLSM-type of products (Controlled Low Strength Materials, i.e. "flowable fill"); and, it is probably also very suitable for cement replacement in making concrete.

ASTM C 618 for coal fly ash classifies a value of 34% retained (i.e., 66% passing) on the No. 325 sieve as satisfactory for use in concrete. Based upon this criterion for pulverized coal fly ash, the PCA wood fly ash easily met this requirement; and, the precipitator ash just barely did not meet this requirement of ASTM C 618.

Test data for particle size analysis in accordance with the modified ASTM C 422 are presented in Fig. 1,2, and 3. Appendix 1 provides the details of this modified ASTM test. These figures show that the gradation is reasonably uniform.

Unit Weight

Unit weight (i.e., bulk density) of the three wood ashes was determined in accordance with the ASTM Test Designation C 29. Table 5 provides the test results. The results show that the Wood fly ash and precipitator ash had similar density values, approximately 25 lb/ft^3, while the bottom ash bulk density was 41 lb/ft^3. This is consistent with the gradation of the bottom ash, which showed a significant amount of coarser fractions of ash materials. These data indicate that the bottom ash may be suitable for replacing regular, normal-weight, sand and coarse aggregates in making lightweight CLSM and/or concrete. Such lightweight construction materials are well suited for insulating fill for roofs and walls, as well as sound and/or ground vibration barriers. Typical manufactured lightweight sand costs over $50 per ton and light weight coarse aggregates costs about $45 per ton. Bulk density value is also necessary for calculations for establishing and modifying cement-based construction materials mixture proportioning. Percentage of voids in Table 5 indicate amount of free space available for packing of other materials in making cement-based materials. The higher the percent voids, the higher the amount of other materials necessary for making cement-based materials.

Specific Gravity

Specific gravity tests for the wood fly ash and precipitator ash were conducted in accordance with the ASTM Test Designation C 188. Test results are provided in Table 6. Results show that the specific gravity value for the two wood ashes is similar, approximately 2.45 (ranges between 2.41 and 2.48). This is a similar order of magnitude as a typical coal fly ash, though the PCA wood ashes have a slightly higher specific gravity value than typical Class F coal fly ash, and slightly lower than typical Class C fly ash. It is also noted from Table 6 that the specific gravity tested for samples passing #100 sieve is slightly higher than that tested for as received samples. This may be contributed to the fact that coarse fraction of the wood ashes contain higher amounts of carbon than the finer fraction. Specific gravity value is necessary for determining relative substitution rate for fly ash versus amount of cement or sand replaced in a mixture; and, also for calculations for establishing and modifying cement-based construction materials mixture proportions.

Specific gravity tests for the bottom ash were carried out in accordance with ASTM Test Designation C128. Test results are shown in Table 7. The bottom ash had an average specific gravity of about 1.65. This is considerably lower than that for typical aggregates used in concrete, which is around 2.65. Therefore, this source of bottom ash should be useful as lightweight aggregates.

SSD Absorption

For the bottom ash, saturated surface dry (SSD) moisture absorption test in accordance with the ASTM Test Designation C 128 was conducted. Results are shown in Table 8. The bottom ash had an SSD absorption value of about 7 percent. This is considerably higher than that for typical sand used in concrete, which is typically less than 2%, but is of a similar order of magnitude as coarse bottom ash from coal-burning plants. SSD moisture absorption value is required for calculations for establishing and modifying cement-based construction materials mixture proportioning. Higher absorption materials may lead to better curing of the cement-based materials after they are cast; and, therefore, better quality for such materials.

ASTM C 618 TESTS

Physical Properties per ASTM C 618

ASTM C 618 provides standard specifications for coal fly ash for use in concrete. There is no other similar test standards available for wood ashes. Therefore, to judge the suitability of the PCA wood ash resource for potential use as a mineral admixture in cement-based materials, physical tests were performed as described below in accordance with the ASTM Test Designation C 618. The following physical properties of the wood ash and the precipitator ash were determined: (1) Cement Activity Index; (2) Water Requirement; and, (3) Autoclave Expansion.

Cement Activity Index

Cement activity index tests for the wood fly ash and the precipitator ash were performed in accordance with the ASTM Test Designation C 311/C 109. Two-inch cubes were made in a prescribed manner using a mixture of cement, sand, and water, without any wood ash (Control mixture). Compressive strength tests were conducted at the age of 3-, 7-, and 28-day. Actual strength test results, in psi, are reported in Table 9 for these test specimens made from the Control mixture. Two additional test mixtures were prepared using 80% cement and 20% wood ash, by weight (instead of cement only without wood ash as in the Control mixture). Four mixtures were made with the two types of fine wood ash being evaluated in this study. Cube compressive strength test results, in psi, for these wood ashes are reported in Table 9.

Comparison of the two wood ash mixtures cube compressive strengths, with the Control mixture, is reported in Table 10. These results are designated as Strength Activity Index with Cement. In this comparison, the Control mixture was assigned a value of 100, at each age, and all other cube compressive strength values were scaled from this reference datum.

For the fly ash mixture, the 3-day, 7-day, and 28-day cube compressive strength test results, Table 10, were below the Control mixture without wood fly ash by about 15 percent. The fly ash sample passes the ASTM C 618 requirement for Cement Activity Index. Overall the PCA fly ash Activity Index with Cement test results show that the fly ash is suitable for making medium strength (say up to 5,000 psi compressive strength) concrete and CLSM (which by the ACI Committee 229 Definition has up to 1,200 psi compressive strength).

The cube compressive strength test results, Table 9, for the precipitator ash mixtures were all significantly lower than that for the Control mixtures without fly ash. The Activity Index with Cement data, Table 10, show about 70% value (lower than 75%

required by ASTM C 618) for the compressive strength compared with the Control mixture without the precipitator ash. However, the actual test data, Table 9, show that sufficient compressive strength can be achieved with the precipitator ash even though the precipitator ash mixture did not perform as well as the no ash Control mixture or the fly ash mixtures. Overall, based upon the cube compressive strength data, it can be concluded that the precipitator ash is suitable for making CLSM, including for making slightly lower strength (say up to 4,000 psi compressive strength) concrete for base course and/or sub-base course for pavement of highways, roadways, and airfields; parking lots; and other similar construction applications.

ASTM C 618 classifies a value at 7-day or 28-day age of 75 or above for the Activity Index with Cement for coal fly ash as passing. Based upon this criterion, the wood fly ash passes and the precipitator does not pass at 7- and 28 day ages but passes at the 3-day age.

Water Requirement

Water requirement tests for the fly ash and the precipitator ash were performed in accordance with the ASTM Test Designation C 311. This test determines the relative amount of water that may be required for mixture proportioning of cement-based construction materials. It is well established that the lower the water required for a desired value of workability for the cement-based material, the higher the overall quality of the product. Test data for water requirement are reported in Table 11. The results show that the average values for water requirement for the two wood ashes tested were higher than the maximum desirable relative value for the water requirement. ASTM C 618 specifies a maximum value of 105 or 115, depending upon the type of ash, as acceptable value for water requirement. For coal fly ash the acceptable value is 105, while that for volcanic ash it is 115. The fly ash sample tested had a value of 110, and the precipitator ash had a value of 121% of control. Therefore, it is concluded that the fly ash and the precipitator ash could perform satisfactorily in cement-based construction materials, even though the water required for a desired amount of workability probably would be somewhat higher. This would lead to a slightly higher amount of cement to compensate for the potential negative effects of the higher water content in the mixture.

Autoclave Expansion

Autoclave expansion tests for the fly ash and the precipitator ash were performed in accordance with the ASTM Test Designation C 311/C 151. Paste bar test specimens containing wood ashes were made. They were then subjected to a high-temperature steam bath at approximately 295 psi pressure in a boiler (a pressure cooker meeting the requirements of the ASTM). The test results, given in Table 12, show that the expansion was significantly higher than that for typical coal fly ash. However, the expansion value of 0.63% recorded for the fly ash and 0.55% for the precipitator ash sample were still below the acceptable maximum limit of expansion/contraction of 0.8%, as specified by ASTM C 618 for coal fly ash. Therefore, all PCA ashes tested are acceptable in terms of long-term soundness/durability from the viewpoint of undesirable autoclave expansion. This conclusion is also confirmed by the amount of MgO present, as reported in the results for chemical analysis in Table 14. This table shows that actual value of MgO was 1.2%, well below the maximum up to 5% considered to be acceptable (according to experience to maximize soundness/durability due to undesirable autoclave expansion/contraction).

Table 13 shows physical properties requirements for coal fly ash per ASTM Test C 618.

<u>Chemical Properties per ASTM C 618</u>

Chemical analysis tests were conducted to determine oxides present in the three sources of the wood ash. X-ray fluorescence technique was used to detect the presence of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO), titanium oxide (TiO_2), potassium oxide (K_2O), and sodium oxide (Na_2O). In this method, ignited samples were fused in a 4:1 ratio with lithium carbonate-lithium tetraborate flux and cast into buttons in platinum molds. These buttons were used to measure x-ray fluorescence intensities for the desired element, in accordance with standard practice for cementitious materials, by using an automated Philips PW1410 x-ray spectrometer. The percentages of each element were derived from the measured intensities through a standardized computer program based on a procedure outlined for low-dilution fusion. This is a "standard practice" for detecting oxides in cementitious compounds, including coal fly ash. Tests are reported in Table 14. Loss on ignition (LOI), moisture content, and available alkali (Na_2O equivalent) for the pre-dried wood ashes were also determined. These test results are also reported in Table 14. According to the oxide analysis data, the fly ash and the precipitator ash do not meet Class C or F coal fly ash requirements due to their high LOI, high available alkali content, and high sulfate contents. The calcium oxide content for the fly ash and the precipitator ash is judged to be very good because the calcium oxide values are above 10 percent. Furthermore, the magnesium oxide values are judged to be quite low enough to minimize the soundness/durability related problems created due to a high MgO value, which is accepted to be greater than five percent. In general all oxides present, except the available alkali (Na_2O equivalent, LOI, and the sulfate content), were within limits specified in the ASTM C 618.

Available alkali was higher, for the fly ash and the precipitator ash, which was expected because these wood ashes are from relatively low-temperature combustion of wood products. It was 0% in the bottom ash sample. Maximum amount of available alkali for coal fly ash is limited to 1.5% in accordance with the ASTM C 618. The actual values were 2.1 and 1.6% in the fly ash and the precipitator ash, respectively. The presence of high amount of alkali may lead to desirable early hydration reaction products in coal fly ash, natural pozzolans, ground granulated blast-furnace slag, silica fume, and/or metakaoline types of reactive-powder additives used in making cement-based construction materials. Available alkali may also impact cement-based construction materials negatively (developing "ASR", alkali silica reaction) if it contains free-silica-based compounds in coarse or fine aggregates used for making such construction materials. Furthermore, higher amounts of available alkali may also lead to chemical combination with sulfates and leaching of such sulfate-based white compounds ("precipitates") on the surface of concrete (called efflorescence) creating undesirable, randomly distributed, white coloring on the concrete surface.

Loss on ignition (LOI) for all three wood ashes is higher (approximately 13, 15, and 10%, respectively, for fly ash, precipitator ash, and bottom ash) than that permitted (maximum 6%) by ASTM C 618 for coal fly ash. However, under certain circumstances, up to 12% maximum LOI is permitted by ASTM C 618. Therefore, based upon the LOI data, these wood ashes are within range of permissible LOI per ASTM C 618 for cement-based construction materials (e.g., CLSM). Recent research at the UWM Center for By-Products Utilization show that high LOI coal fly ash can be effectively used for CLSM as well as roller compacted concrete pavements. Currents practice in Wisconsin and elsewhere also show that high LOI coal fly ash should generally perform satisfactorily for CLSM. In conclusion, therefore, the PCA wood fly ash, precipitator ash, and bottom ash can be used for CLSM and concrete, no-fines concrete, roller compacted concrete pavements, dry-cast concrete products, etc. which do not require the use of air-entraining agent for freezing and thawing resistance of concrete.

MINERAL ANALYSIS

The mineral analysis for the three wood ashes were conducted by using XRD. The results are shown in Table 15. The fly ash and the precipitator ash contained approximately 61% glass phase, which was a little bit lower than typical coal fly ash (around 80%). As can be expected, bottom ash contained higher amounts of glass phase because it was cooled rapidly in water. Therefore, there was not enough time for the crystal phases to form. Since the glass contents of fly ash contributes to its potential pozzolanic reactivity, a higher amount of glass phase is preferred when fly ash is used as cementitious materials. Except for anhydrite and lime, the crystal phases listed in Table 14 have little pozzolanic reactivity.

ELEMENTAL ANALYSIS

The three wood ash samples were analyzed for total chemical make-up by the Instrumental Neutron Activation Analysis (INAA). Knowledge of total elemental concentration is necessary because it provides an insight into the possibility of leaching potential characteristics of the material tested. Leaching of trace metals is known to be highly dependent upon the temperature of the combustion in the boiler and how these trace elements are converted to chemical compounds. A high concentration of undesirable elements does not necessarily mean that these undesirable elements will leach. Tests for leachate characteristics of materials, such as TCLP, must be performed in order to conduct the environmental assessment of the materials proposed to be used and the product (e.g., cement-based materials) to be made from it. The results for the elemental analysis performed are reported in Table 16.

SCANNING ELECTRON MICROSCOPY (SEM)

A scanning electron microscope available at the University of Wisconsin Milwaukee was employed for this part of the investigation. SEM pictures (photomicrographs) for the three wood ashes were obtained, given in Figures 4 through 25. These SEM pictures are an important part of understanding the character and morphology of the particles of the product being evaluated for considering their constructive use options. For example, studying the morphology allows judgment to be made regarding the physical and/or mechanical bond that might be possible for the wood ash in creating new cement-based construction materials. Also, it allows an opportunity to study the contours of the particles and how they may help in mixing and manufacturing these cement-based materials. The particle morphology helps in understanding the level of completeness of combustion and microstructure of burned, partially burned, or unburned particles. This evaluation of level of combustion, and particle size and distribution, also help in judging the water demand that may be placed upon for making cement-based materials.

All three wood ash SEM micrographs can be observed to be composed of heterogeneous mixture of particles of varying size.

Some glass-type material is present. Partially hydrated, unhydrated, and hydrated compounds of calcium are also present. Unlike coal fly ash particles, these wood ash particles are mostly not spherical in shape. They are generally angular. Also, all of these wood ash particles are not observed to be solid but some of them are cellular in form. These cellular particles are mostly unburned or partially burned wood or bark particles.

Section 2

Constructive Use Options for PCA Wood Ashes

INTRODUCTION

A number of uses of coal combustion by-products in construction materials already exist [1]. However, these applications depend greatly upon physical, chemical, mineralogical, and surface properties of such by-products. The same is true for the PCA wood ashes. The following sections deal with potential uses of these wood ashes analyzed in this investigation.

USES OF PCA WOOD ASHES

The size distribution of the PCA wood ashes is not similar to that of conventional coal fly ash. PCA wood ashes are not as fine as typical coal fly ash. Furthermore, the PCA wood ashes are angular not spherical. This means that if such wood ashes are added in mortar or concrete then workability of fresh mortar or concrete will not be helped. In fact, some porous particles of unburned or partially burned wood (charcoal) may absorb the water added in mortar or concrete and further reduce the workability of the mixture.

This investigation revealed that the PCA wood ash samples generally do not conform to ASTM C 618 Class F or C requirements for applications in cement-based composites. However, these wood fly ashes are suitable for use in medium-strength (up to 5,000 psi) mortars and concrete. These sources of wood fly ashes are also very suitable for CLSM and grouting applications.

In many other applications in which conventional coal fly ashes are used, the PCA wood ash generally cannot be used. However, the PCA wood ashes probably can be used effectively for many more applications after it is beneficiated; for example, after sieving coarser fractions and/or removing undesirable charcoal particles. For more useful applications, after beneficiating wood fly ash, further study would be needed to develop optimum use options. A list of potential uses of the PCA wood ash is presented in Table 17.

Section 3

Suggestions for Further Evaluations

As indicated in Section 2, the PCA wood ashes have considerable potential for many applications. However, the performance of these wood ashes needs to be established for individual applications.

The following are some of the high-volume applications that would require further evaluation. It is anticipated that these applications can consume most of the wood ash products produced by PCA.

FLOWABLE MATERIALS

Large amounts of PCA wood ashes can be utilized in manufacture of flowable fill (a.k.a. manufactured dirt) material. This is defined by ACI Committee 229 as Controlled Low-Strength Material (CLSM). The compressive strength of CLSM can be very little (10 psi) up to 1200 psi. This material can be used for foundations, bridge abutments, buildings, retaining walls, utility trenchs, etc. as backfill; as embankment, grouts, abandoned tunnel and mine filling for stabilization of such cavities, etc. See Table 17 for more details.

CLSM can be manufactured with large amounts of PCA wood ash, low (or zero) amount of cement and/or lime, and high water-to-cementitious materials ratio to produce the flowable fill. An evaluation study is highly (very strongly) recommended in order to produce CLSM for various applications with this material for approval by local environmental agencies, such as Wisconsin Department of Natural Resources.

BRICKS, BLOCKS, AND PAVING STONES

The PCA wood ashes have potential for applications in numerous masonry products such as bricks, blocks, and paving stones. Additionally, these wood ashes can be utilized as a replacement of clay in manufacture of clay bricks. However, in order to meet the ASTM requirements for strength and durability, testing and evaluation work is necessary. The results of such testing would be used in developing specifications for the PCA ash in the manufacture of masonry products. Lab evaluation is strongly recommended.

MEDIUM-STRENGTH CONCRETE

The PCA wood ashes can be used as a partial replacement of sand and/or cement in concrete. This is a very broad conclusion from the work conducted as a part of this test evaluation. Test results show that these wood ashes generally did not meet ASTM C 618 requirements for concrete products applications. However, the ASTM C 618 is written exclusively for coal fly ash (and natural/volcanic ash) materials. Future ASTM standards, therefore, may evolve which could be satisfied by the PCA wood ashes. In order to determine the effects of optimum inclusion of the these ashes on concrete strength and durability properties, lab study is strongly recommended.

BLENDED CEMENT

The highest market value use of the PCA wood ashes is in the production of blended cements. Blended cement material is typically composed of portland cement, coal fly ash, and/or other cementitious materials, and chemicals. The PCA ashes have significant available alkali content (above the maximum allowed by ASTM C 618, Table 14). The high alkali content, however, could be a desirable characteristic for activating chemical reactions for cementing-ability of blended cements for various applications. Further evaluation is recommended.

ROLLER-COMPACTED CONCRETE PAVEMENT

The PCA wood ashes can be used for Roller-Compacted Concrete Pavement (RCCP) for improving the performance and use of log-yards in all types of Wisconsin weather. Log-yards pavings for PCA would be very important application. RCCP popularity is increasing in Wisconsin. Lab evaluation is highly recommended for future applications.

SOIL AMENDMENT WITH DREDGED MATERIALS

Wisconsin dredges a significant tonnage of dredged materials for the great lakes and the Mississippi River to keep the navigation channels open. The PCA wood ashes (fly ash, precipitator ash, and the bottom ash) would be an excellent additive to dredged materials to make manufactured topsoil for use in Christmas tree farms, sod farms, potting soil, pulp-mill new growth woods/plantations, etc. These wood ashes will act as a desiccant, deodorizer, and chemical activators for dredged materials. The resulting manufactured topsoil can be used as a fertilizer, and to decrease subsurface porosity and improve infiltration characteristics of soils. Further lab study is recommended.

PACKAGING CORPORATION OF AMERICA WOOD ASH CHARACTERIZATION
(Fly Ash, Precipitator Ash, and Bottom Ash)

Table 1: As-Received Moisture Content of Wood Ash

Ash Source	Moisture Content, %	
	Actual	Average
Fly Ash	24.2	23.7
	23.1	
Precipitator Ash	29.4	29.5
	29.6	
Bottom Ash	69.4	68.8
	68.1	

PACKAGING CORPORATION OF AMERICA
WOOD ASH PARTICLE SIZE ANALYSIS

Table 2: Sieve Analysis of Wood Ash (As-Received Samples)
(Tests conducted per ASTM C 136)

Fly Ash		
Sieve Size	% Passing*	ASTM C 33 % Passing
3/8" (9.5-mm)	100	100
#4 (4.75-mm)	99.7	95 to 100
#8 (2.36 mm)	99.1	80 to 100
#16 (1.18 mm)	93.2	50 to 85
#30 (600 μm**)	85.7	25 to 60
#50 (300 μm**)	82.0	10 to 30
#100 (150 μm**)	77.4	2 to 10

Precipitator Ash		
Sieve Size	% Passing*	ASTM C 33 % Passing
3/4" (19.1-mm)	100	100
1/2" (12.7-mm)	100	100
3/8" (9.5-mm)	100	100
#4 (4.75-mm)	99.3	95 to 100
#8 (2.36 mm)	98.1	80 to 100
#16 (1.18 mm)	92.2	50 to 85
#30 (600 μm**)	71.7	25 to 60
#50 (300 μm**)	55.8	10 to 30

#100 (150 μm**)	43.4	2 to 10

* Values reported for % passing are the average of two tests.

** 1.0 μm = 10^{-6} m

Table 2 (cont'd): Sieve Analysis of Wood Ash (As-Received Samples) (Continued)
(Tests conducted per ASTM C 136)

Bottom Ash		
Sieve Size	% Passing*	ASTM C 33 % Passing
1" (25.4-mm)	98.4	100
3/4" (19.1-mm)	95.0	100
1/2" (12.7-mm)	84.3	100
3/8" (9.5-mm)	78.1	100
#4 (4.75-mm)	62.2	95 to 100
#8 (2.36 mm)	48.6	80 to 100
#16 (1.18 mm)	36.9	50 to 85
#30 (600 μm**)	27.2	25 to 60
#50 (300 μm**)	20.2	10 to 30
#100 (150 μm**)	13.6	2 to 10

* Values reported for % passing are the average of three tests.

** 1.0 μm = 10^{-6} m

Table 3: Material Finer Than No. 200 Sieve by Washing (As-Received Samples)
(Tests conducted per ASTM C 117)

Ash Source	Received Date	Material Finer than No. 200 Sieve (%)	
		Actual	Average
Fly Ash	2/26/99	72.7	74.1
		75.4	
Precipitator Ash	2/26/99	54.9	53.1
		51.3	
Bottom Ash	2/26/99	8.6	8.3
		8.0	

Table 4: Materials Retained on No. 325 Sieve
(Tests conducted per ASTM C 311/C 430)

Ash Source	Delivery Date	% Retained on No. 325 Sieve (As-Received Sample)	
		Actual	Average
Fly Ash	2/26/99	26.0	25.0
		24.0	
Precipitator Ash	2/26/99	36.3	37.4

		38.4	

PCA WOOD ASH

UNIT WEIGHT, VOIDS, AND SPECIFIC GRAVITY

Table 5: Unit Weight and Voids
(Tests conducted on as-received samples per modified ASTM C 29,
utilizing 400 ml measure)

Ash Source	Received Date	Unit Weight (lbs/ft^3)		Voids (%)	
		Actual	Average	Actual	Average
Fly Ash+	2/26/99	24.30	24.7	84.1	83.9
		25.1		83.6	
Precipitator Ash+	2/26/99	24.5	24.5	83.7	83.8
		24.4		83.8	
Bottom Ash++	2/26/99	41.0	41.1	57.2	57.4
		41.2		57.5	

\+ Tested using a 400 ml volume container
++ Tested using a 1/4 ft^3 volume container

Table 6: Specific Gravity
(Tests Conducted per ASTM C 311/C 188)

Ash Source	Received Date	Specific Gravity*	
		Actual	Average
Fly Ash*	2/26/99	2.45	2.45
		2.45	
Precipitator Ash*	2/26/99	2.37	2.41
		2.45	
Fly Ash Passing #100**	2/26/99	2.47	2.46
		2.45	
Precipitator Ash Passing #100**	2/26/99	2.45	2.48
		2.51	

* Fly ash & precipitator ash samples were first sieved over No. 20 sieve. Tests were conducted on the ash that passed through the No. 20 sieve (also used for hydrometer, autoclave expansion, and mortar cubes). Specific gravity reported are for particles passing No. 20 sieve.

** Fly ash & precipitator ash samples were first sieved over No. 100 sieve. The specific gravity of this size fraction is required for the particle size distribution obtained from ASTM D 422 Hydrometer Analysis

Table 7: Specific Gravity
(Tests Conducted per ASTM C 128)

Ash Source	Received Date	Bulk Specific Gravity		Bulk Specific Gravity (SSD Basis)		Apparent Specific Gravity	
		Actual	Average	Actual	Average	Actual	Average
Bottom Ash*	2/26/99	1.47	1.55	1.58	1.66	1.65	1.75
		1.62		1.74		1.85	

Table 8: Absorption
(Tests Conducted per ASTM C 128)

Ash Source	Received Date	SSD Absorption, %	
		Actual	Average
Bottom Ash*	2/26/99	7.3	7.5
		7.7	

* This ash sample was first sieved over No. 4 sieve. Tests were conducted on the ash that passed through this No. 4 sieve since the procedure of ASTM C 128 is for specific gravity for fine aggregates. Other ash sources were not tested for absorption because they were not coarse enough.

PCA WOOD ASH

ASTM C 618 PHYSICAL PROPERTIES

Table 9: Mortar Cube Compressive Strength*
(Tests conducted per ASTM C 311/C 109)

Ash Source	Received Date	Compressive Strength (psi)+		
		3-Day	7-Day	28-Day
Control	NA	3145	4080	5310
**Fly Ash	2/26/99	2760	3390	4360
**Precipitator Ash	2/26/99	2380	2910	3550

* ASTM C 311 is used in conjunction with ASTM C 618 for evaluation of strength development of mineral admixtures with portland cement. A mineral admixture is added as replacement of cement for the test mixture. For this reason, the finer fraction of the fly and precipitator ashes were utilized to better reflect the potential reactivity of the ashes. The finer material has increased surface area and, therefore, would have increased potential for reactivity. Each result is an average of three compression tests.

** This ash sample was first sieved over No. 20 sieve. Tests were conducted on the ash that passed through the No. 20 sieve.

* The ash blend mixtures were 80% portland cement and 20% fly ash (or precipitator ash) as required by ASTM C 311/ C 109

Table 10: Strength Activity Index with Cement*+
(Tests conducted per ASTM C 311/C 109)

Ash Source	Received Date	3-day Test %	7-Day Test %	28-Day Test %
Control	N/A	100.0	100.0	100.0
**Fly Ash	2/26/99	87.8	83.1	82.1
**Precipitator Ash	2/26/99	75.7	71.3	66.9

* Results obtained from the mortar cube compressive strength results.

** This ash sample was first sieved over No. 20 sieve. Tests were conducted on the ash that passed through the No. 20 sieve.

+ The ash blend mixtures were 80% portland cement and 20% fly ash (or precipitator ash) as required by ASTM C 311/ C 109

Table 11: Water Requirement*
(Tests conducted per ASTM C 311)

Ash Source	Received Date	Water Requirement (% of Control)		ASTM C 618 Specifications	
		Actual	Average	Class C	Class F
**Fly Ash	2/26/99	110	110	105 max	105 max
		110			
**Precipitator Ash	2/26/99	121	121		
		121			

* Results obtained for the mortar cube mixtures.

** This ash sample was first sieved over No. 20 sieve. Tests were conducted on the ash that passed through the No. 20 sieve.

Table 12: Autoclave Expansion or Contraction
(Tests conducted per ASTM C 311/C 151)

Ash Source	Received Date	Autoclave Expansion (%)	
		Actual	Average
*Fly Ash	2/26/99	0.66	0.63
		0.60	
*Precipitator Ash	2/26/99	0.54	0.55
		0.55	

* This ash sample was first sieved over No. 20 sieve. Tests were conducted on the ash that passed through the No. 20 sieve.

Table 13: Physical Test Requirements of Coal Fly Ash per ASTM C 618 - 97

TEST	ASTM C 618 SPECIFICATIONS		
	CLASS N	CLASS C	CLASS F
Retained on No.325 sieve, (%)	34 max	34 max	34 max
Strength Activity Index with Cement at 7 or 28 days, (% of Control)	75 min	75 min	75 min
Water Requirement (% of Control)	115 max	105 max	105 max
Autoclave Expansion, (%)	±0.8	±0.8	±0.8
Specific Gravity	-	-	-
Variation from Mean, (%) Fineness Specific Gravity	 5 max 5 max	 5 max 5 max	 5 max 5 max

PCA WOOD ASH ASTM C 618
CHEMICAL PROPERTIES

Table 14: Chemical Analysis (oxides, LOI, moisture content, available alkali)
(Tests conducted on as-received samples)

OXIDES, SO_3, AND LOSS ON IGNITION ANALYSIS, (%)					
Analysis Parameter	Ash Source			ASTM C 618 - 97 Requirement	
	Fly Ash	Precipitator Ash	Bottom Ash	Class C	Class F
Silicon Dioxide, SiO_2	29.0	29.0	43.0	--	--
Aluminum Oxide, Al_2O_3	12.6	10.8	16.8	--	--
Iron Oxide, Fe_2O_3	16.3	16.7	20.8	--	--
SiO_2 + Al_2O_3 + Fe_2O_3	57.9	56.5	80.6	50.0, Min.	70.0, Min.
Calcium Oxide, CaO	14.3	15.8	4.2	--	--
Magnesium Oxide, MgO	1.2	1.2	1.0	--	--
Titanium Oxide, TiO_2	0.7	0.5	0.8	--	--
Potassium Oxide, K_2O	3.0	2.6	2.1	--	--
Sodium Oxide, Na_2O	1.8	1.5	0.5	--	--
Sulfate, SO_3	8.4	6.6	0.5	5.0, Max.	5.0, Max.
Loss on Ignition, LOI (@ 750 C)	12.7	15.3	10.4	6.0, Max.	6.0, Max.*
Moisture Content	1.2	0.2	0.2	3.0, Max.	3.0, Max.
Available Alkali, Na_2O Equivalent (ASTM C-311)	2.1	1.6	0.0	1.5, Max.**	1.5, Max.**

* Under certain circumstances, up to 12.0% max. LOI may be allowed.

** Optional. Required for ASR Minimization.

PCA WOOD ASH
CHEMICAL COMPOSITION

Table 15: Mineralogy of Wood Ash

MINERALOGY (% by Weight)			
Analysis Parameter	Fly Ash	Precipitator Ash	Bottom Ash
Amorphous	60.8	61.5	73.3
Magnetite, Fe_3O_4	11.7	12.9	17.5
Anhydride, $CaSO_4$	6.8	6.7	*
Mullite, $Al_2O_3.SiO_2$	5.2	1.9	*
Hematite, Fe_2O_3	4.8	4.5	9.3
Quartz, SiO_2	4.1	6.0	*
Calcite, $CaCO_3$	3.9	3.3	*
Lime, CaO	2.0	3.4	*
Cristobalite, SiO_2	0.6	*	*

* Not Detectable

PCA WOOD ASH ELEMENTAL ANALYSIS

Table 16: Elemental Analysis (As-Received Sample)

ELEMENTAL (BULK CHEMICAL) ANALYSIS (Average of two samples unless noted otherwise)			
Element	Material		
	Fly Ash (ppm)	Precipitator Ash (ppm)	Bottom Ash (ppm)
	Received Date	Received Date	Received Date
	2/26/99	2/26/99	2/26/99
Aluminum (Al)	37553.3	29147.5	45969.2
Antimony (Sb)	33.8	14.5	4.6
Arsenic (As)	477.1	267.4	< 141.5*
Barium (Ba)	< 232.2*	< 229.3*	< 128.9*
Bromine (Br)	13.6	6.8	< 3.7*
Cadmium (Cd)	< 8096.0*	< 6075.4*	< 6330.6*
Calcium (Ca)	11685.9	11385.6	4025.5
Cerium (Ce)	15.3	7.9	50.7
Cesium (Cs)	8.1	3.9	3.9
Chlorine (Cl)	< 408.4*	< 365.2*	< 186.1*
Chromium (Cr)	98.7	54.7	57.3
Cobalt (Co)	14.1	8.2	9.3
Copper (Cu)	< 752.3*	< 676.2*	< 368.1*
Dysprosium (Dy)	< 10.6*	< 9.9*	< 5.2*

* Detection Limit

Table 16: Elemental Analysis (As-Received Sample) (Continued)

ELEMENTAL (BULK CHEMICAL) ANALYSIS (Average of two samples unless noted otherwise)			
Element	Material		
	Fly Ash (ppm)	Precipitator Ash (ppm)	Bottom Ash (ppm)
	Received Date	Received Date	Received Date
	2/26/99	2/26/99	2/26/99
Europium (Eu)	0.6	0.4	0.6
Gallium (Ga)	< 910.2*	< 857.4*	< 432.6*
Gold (Au)	< 0.0*	< 0.0*	< 0.0*
Hafnium (Hf)	1.3	0.9	0.4
Holmium (Ho)	< 62.4*	< 41.9*	< 62.0*
Indium (In)	< 0.9*	< 0.8*	< 0.4*
Iodine (I)	< 27.1*	< 25.2*	< 13.1*
Iridium (Ir)	< 0.0*	< 0.0*	< 0.0*
Iron (Fe)	81285.8	58809.1	102591.5
Lanthanum (La)	30.8	18.9	32.4
Lutetium (Lu)	1.1	0.7	0.9
Magnesium (Mg)	< 3010.6*	< 2506.6*	3188.3
Manganese (Mn)	14072.3	13607.5	6736.4
Mercury (Hg)	8.2	5.3	7.7

* Detection Limit

Table 16: Elemental Analysis (As-Received Sample) (Continued)

ELEMENTAL (BULK CHEMICAL) ANALYSIS (Average of two samples unless noted otherwise)			
Element	Material		
	Fly Ash (ppm)	Precipitator Ash (ppm)	Bottom Ash (ppm)
	Received Date	Received Date	Received Date
	2/26/99	2/26/99	2/26/99
Molybdenum (Mo)	< 283.6*	< 212.1*	< 202.1*
Neodymium (Nd)	< 14.5*	8.5	14.2
Nickel (Ni)	2335.7	< 2082.2*	< 2178.4*
Palladium (Pd)	< 1542.2*	< 1450.0*	< 728.4*
Potassium (K)	< 17038.4*	13703.7	< 5670.8*
Praseodymium (Pr)	< 758.8*	< 492.1*	< 813.6*
Rubidium (Rb)	189.4	114.3	110.3
Rhenium (Re)	< 4703.5*	< 3733.6*	< 4108.4*
Ruthenium (Ru)	17.4	11.7	5.5
Samarium (Sm)	7.2	4.1	4.8
Scandium (Sc)	8.3	4.9	7.6
Selenium (Se)	922.4	358.6	< 110.3*
Silver (Ag)	< 16.9*	< 12.3*	< 12.9*
Sodium (Na)	6592.3	4801.0	1910.8

* Detection Limit

Table 16: Elemental Analysis (As-Received Sample) (Continued)

ELEMENTAL (BULK CHEMICAL) ANALYSIS (Average of two samples unless noted otherwise)			
Element	Material		
	Fly Ash (ppm)	Precipitator Ash (ppm)	Bottom Ash (ppm)
	Received Date	Received Date	Received Date
	2/26/99	2/26/99	2/26/99
Strontium (Sr)	< 38.6*	< 28.2*	< 26.8*
Tantalum (Ta)	0.9	0.8	0.6
Tellurium (Te)	0.8	0.4	< 0.5*
Terbidium (Tb)	< 0.6*	< 0.4*	< 0.5*
Thorium (Th)	5.9	3.4	4.8
Thulium (Tm)	8.7	7.4	7.0
Tin (Sn)	< 432.5*	< 315.4*	< 310.0*
Titanium (Ti)	2927.5	< 2696.4*	2390.1
Tungsten (W)	< 55.7*	< 42.9*	< 47.0*
Uranium (U)	42.4	24.3	32.3
Vanadium (V)	332.3	195.8	283.1
Ytterbium (Yb)	4.3	3.5	5.2
Zinc (Zn)	< 43.7*	< 157.2*	< 23.6*
Zirconium (Zr)	< 188.0*	< 136.7*	< 144.0*

* Detection Limit

Table 17: Potential Uses of the PCA Wood Ashes

Type of Application			PCA Wood Ashes
HIGH TECHNOLOGY APPLICATIONS			
1.	Recovery of Materials		Low
2.	Filler Material for Polymer Matrix (plastic)		Very Low
3.	Filler Material for Metal Matrix Composites		Very Low
4.	Other Filler Applications:		
	a.	Asphaltic roofing shingles	Low
	b.	Wallboard	High
	c.	Joint filler compounds	Low
	d.	Carpet backing	Low
	e.	Vinyl flooring	Low
	f.	Industrial coatings	Very Low
5.	Super Pozzolanic Materials (beneficiated fly ash)		Medium
MEDIUM TECHNOLOGY APPLICATIONS			
1.	Manufacture of Blended Cement		High
2.	Manufacture of Lightweight Aggregates:		
	a.	Fired	High
	b.	Unfired	Medium
3.	Manufacture of Concrete Products:		
	a.	Low-strength concrete	Very High
	b.	Medium-strength concrete	Very High
	c.	High-strength concrete	Very Low
	d.	Lightweight concrete	High
	e.	Prestressed/precast concrete products	Low
	f.	Roller compacted concrete	Very High
	g.	No-fines and/or Cellular concrete	Very High
4.	Filler in Asphalt Mix		Medium
5.	Bricks:		
	a.	Unfired bricks	High
	b.	Fired bricks	Very High
	c.	Clay bricks	Very High

Table 17: Potential Uses of the PCA Wood Ashes (cont'd)

Type of Application	PCA Wood Ashes
6. Blocks:	
Building blocks	Very High
Decorative blocks	High
7. Reefs for Fish Habitats	Very High
8. Paving Stones	Very High
9. Stabilization of Municipal Sewage Sludge	Very High
10. Waste Stabilization:	
Inorganic wastes*	High
Organic wastes*	Very High
Combined complex wastes	Low
11. Ceramic Products	Low
LOW TECHNOLOGY APPLICATIONS	
1. Backfills:	
Bridge abutment, buildings, etc.	Very High
Trench and excavation backfills	Very High
2. Embankments	Very High
3. Site Development Fills	Very High
4. Stabilization of Landslides – Grouting	Very High
5. Landfill Cover (as a substitute for soil cover)	Very High
6. Pavement Base and Sub-base Courses:	
Combination with lime or cement and coarse aggregate	Very High
Combination with cement or lime	Very High
Combination with on-site soils with or without the addition of lime or cement	Very High
7. Subgrade Stabilization or Soil Stabilization:	
Roadways/Highways	High
Parking areas	High
Runways	High

*Or a combination of inorganic and organic dredged materials from the Great Lakes and/or the Mississippi River.

Table 17: Potential Uses of the PCA Wood Ashes (cont'd)

Type of Application	PCA Wood Ashes
8. Land Reclamation:	
Agriculture	Very High
Turf-grass (for example golf courses)	Very High
Park land	Very High
9. Soil Amendment (agriculture and/or potting soil)*:	
Improve infiltration characteristics	Very Low
Decrease Subsurface porosity	Very High
Fertilizer/Composting	Very High
10. Slurried Flowable Fly ash	Very High
MISCELLANEOUS CIVIL ENGINEERING APPLICATIONS	
1. Backfills:	
Between foundations and existing soil	Very High
Retaining walls	Very High
Utility trenches	Very High
2. Excavation in Streets and around Foundation	Very High
s for Abandoned Tunnels, Sewers and other Underground Facilities cluding mines)	Very High
4. Grouts	Very High
5. Hydraulic Fills	Very High

* With or without other products, such as dredged materials.

PARTICLE SIZE ANALYSIS

SCANNING ELECTRON MICROGRAPHS OF PCA WOOD ASHES

FIGURE 4: Fly Ash, 100X Magnification

FIGURE 5: Fly Ash, 500X Magnification

FIGURE 6: Fly Ash, 1000X Magnification

FIGURE 7: Fly Ash, 5000X Magnification

FIGURE 8: Precipitator Ash, 100X Magnification

FIGURE 9: Precipitator Ash, 500X Magnification

FIGURE 10: Precipitator Ash 1000X Magnification

FIGURE 11: Precipitator Ash 5000X Magnification

FIGURE 12: Bottom Ash, Fine 25X Magnification

FIGURE 13: Bottom Ash, Fine 100X Magnification

FIGURE 14: Bottom Ash Fine 500X Magnification

FIGURE 15: Bottom Ash Fine 1000X Magnification

FIGURE 16: Bottom Ash, Fine 2000X Magnification

FIGURE 17: Bottom Ash, Fine 5000X Magnification

FIGURE 18: Bottom Ash, Coarse 25X Magnification

FIGURE 19: Bottom Ash, Coarse 100X Magnification

FIGURE 20: Bottom Ash, Coarse 500X Magnification

FIGURE 21: Bottom Ash, Coarse 1000X Magnification

FIGURE 22: Bottom Ash, Coarse 5000X Magnification

FIGURE 23: Bottom Ash, Coarse #2, 25X Magnification

FIGURE 24: Bottom Ash, Coarse #2, 500X Magnification

FIGURE 25: Bottom Ash, Coarse #2
5000X Magnification

Section 4

References

[1] Naik, T. R., and Singh, S. S., "Fly Ash Generation and Utilization – An Overview," in Recent Trend in Fly Ash Utilization, Ministry of Environment and Forests, Government of India, Bhopal, India, June 1993 (available from the UW – Milwaukee Center for By-Products Utilization).

APPENDIX 1: Modified ASTM C 422 for Particle Size Distribution

Tests conducted at the UWM Center for By-Products Utilization (CBU) had revealed that the standard ASTM C 422 test method is inadequate to measure particle size distribution of fly ashes, and similar fine grained materials, especially below 10-micron size particles. This is partially due to agglomeration caused by very fine particles of fly ash and also potentially due to chemical reaction caused by the cementitious nature of the fly ash. A significant gel formation occurs during the sedimentation testing of the fly ash. Therefore, in order to obtain more accurate test results, a modified ASTM C 422 test method was developed by the UWM Center for By-Products Utilization for measuring particle size distribution of fly ash samples by the sedimentation technique. This UWM-CBU method differs from the standard ASTM C 422 in respect to sample preparation, sedimentation liquid, size of the sedimentation cylinder, and the hydrometer used. In the UWM-CBU procedure, the fly ash sample is not subjected to pretreatment prior to the sedimentation test. The particle concentration in the polymeric suspending liquid used was maintained at about three percent. This new suspending liquid had a specific gravity of about 0.8. This also necessitated the use of a different hydrometer, which can measure the density of the liquid containing suspended particles having specific gravity in the range of approximately 0.8 to 0.9. The size of the sedimentation cylinder was changed to 500 ml instead of 1000 ml used in the standard ASTM C 422 procedure. This was done to more effectively use the sedimentation liquid. In order to measure the particle size distribution, the fly ash test sample and the liquid were added in the sedimentation cylinder and were mixed by inverting the cylinder, with open end closed by hand, 60 times in one minute. Then the sedimentation readings were taken and calculations made in accordance with the ASTM Test C 422 for determination of particle size distribution. Typical results are shown in Fig. 1 to 3.