FINAL TECHNICAL REPORT
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Project Title: **MANUFACTURING AUTOCLAVED AERATED CONCRETE FROM ILLINOIS COAL FLY ASH**

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ABSTRACT

Autoclaved aerated concrete (AAC) is a lightweight, energy-efficient, fire-retardant construction material that is used widely in Europe and Asia. Regular AAC is produced with sand as a major component. The overall goal of this project was to determine the technical and economic feasibility of producing AAC using Illinois coal fly ash as a substitute for sand. Industry partners include: Babb Technologies (Babb), Ameren Energy Fuels & Services Company (Ameren, CIPS), Dynegy Midwest Generation (DMG), Cinergy PSI (CPSI), and Southern Illinois Power Cooperative (SIPC).

Fly ash samples generated from burning Illinois coals from four different sources and collected from electrostatic precipitators were tested using a bench-scale facility at the ISGS during the year 1 (2002-03) project. During year 2 (2003-04) of this project, fly ashes from three new sources and a FBC ash were tested for bench-scale production. A total of more than fifty bench-scale runs have been conducted. AAC blocks containing up to 68-wt% fly ash were successfully produced. The AAC blocks produced with fly ash show compressive strengths comparable to those of regular AAC blocks made without fly ash. In general, these ashes are suitable for use in the production of low density AAC blocks. For higher density AAC panel production, a modification of the formula with additional sand will be necessary.

Environmental leaching studies using simulated acidic rain water show that the amounts of metal ions (As, Ba, Cd, Cr, Hg, Ni, Se, and Pb) leached from the raw materials were below the limits set by the U.S. EPA for other solid waste materials. With an exception of the products made from one specific source, the mercury concentration in the AAC products shows no significant variation in samples before and after autoclaving. The sulphur content of air-dried AAC products compared with that of autoclaved products shows no significant difference. This observation indicates that there is a limited concern for a secondary sulphur emission during AAC product manufacture. The overall results indicate that the fly ash AAC products may be considered environmentally safe building materials.

EXECUTIVE SUMMARY

Autoclaved aerated concrete (AAC) was developed in Europe in 1923. Commercial production of the material began in 1930. AAC is a lightweight, energy-efficient, fire-retardant construction material that is used widely in Europe (about 200 production plants) (Durbral, 1992). The material is a mixture of sand, lime, cement, gypsum, water and an expanding agent, which causes the raw material to rise like bread dough, with countless small air pockets. AAC can be molded and cut into precisely dimensioned units and cured in an autoclave, which steam-cures the concrete under pressure. During this process, the ingredients combine to form calcium silicate hydrate, which establishes the special properties of the finished product. The process produces a material that is only one-fourth to one-third the weight of conventional concrete. AAC is environmental friendly, insect resistant, and has a much better fire-resistance value than wood. Its light weight also makes it easy to use during construction, and its aerated structure gives it better thermal insulation and sound absorption properties than conventional concrete. In most cases, every portion of both the structural and insulation requirements of a building are satisfied with this one material.

In Illinois, the roughly three million tons of coal fly ash produced each year are typically ponded or landfilled and are a readily available raw material for making value-added products. Industry partners of this project include, but are not limited to Babb Technologies (Babb), Precast Autoclaved Aerated Concrete of America (PAACA), Ameren Energy Fuels & Services Company (Ameren, CIPS), Dynegy Midwest Generation (DMG), Cinergy PSI (CPSI), and Southern Illinois Power Cooperative (SIPC). The objectives of this project were: 1) to prepare and perform pilot-scale production-test runs using fly ash from Illinois sources; 2) to assess the chemical, physical, and engineering properties of the products; 3) to conduct environmental suitability tests on the new products; and 4) to provide technical assistance to companies interested in building an AAC production plant in Illinois.

Because our industrial partner has their commercial facility shut down to resolve their business issues, our efforts on scale-up test runs were used to conduct additional bench-scale tests on three new sources of Illinois coal fly ashes. In addition, extensive efforts were made to develop a process for the use of FBC ash in making AAC products. A total of more than fifty bench-scale runs have been conducted. The technical feasibility of the process was evaluated and the products properties were analyzed. The results were optimistic. Once our industry partner's commercial facility is available, conducting pilot-scale test runs is in order.

The bench-scale test results indicate that metal oxide compositions of Class F Illinois dry coal ash and FBC ash samples, in general, met the basic requirement for AAC production as described by the AAC producers, Wehrhahn (2002); Yutong (Wittmann, 1992) and Silbet (Wittmann, 1992), except that the loss on ignition (LOI) of Coffeen fly ash is higher than the 10-wt% defined by Yutong. The slight variations of SiO_2, CaO, and LOI levels in those fly ash samples did not produce problems during small-scale AAC production tests, even though the CaO content in the FBC ash was as high as 16.34%. In Russia, Silbet also had successfully used FBC ash to manufacture AAC products (Wittmann, 1992). Several formulations with fly ash substitutions up to 68-wt% have been tested. The compressive strength of the AAC blocks produced ranged from 245 to 675 psi. In most cases the data are within the range (290-435 psi) of compressive strengths for commercially accepted

AAC. The compressive strength value of FBC AAC block was relatively low, but with some modification of the formulations the compressive strength increased from 245 psi to 452 psi.

The leaching characteristics of the fly ash samples were examined. The concentrations of seven heavy elements (As, Ba, Cd, Cr, Ni, Pb, and Hg) in all the extracts were below the limit set by the U.S. EPA for other solid waste materials (U.S. EPA, 1999). With the exception of the products made from one specific source, the mercury concentration in the AAC products shows no significant variation in samples before and after autoclaving. The mercury concentration of the AAC products from this specific source showed a decrease of the mercury content from 0.04 ppm to 0.01 ppm after autoclaving.The test results indicate that the fly ash samples tested may be considered environmentally safe raw materials. Similar leaching tests of the AAC products also indicated that the seven heavy elements of environmental concern were also below the limit (Chou et al., 2003).

A preliminary economic study for manufacturing AAC using Illinois coal fly ash showed favorable results. Assuming a medium-size AAC plant produces 3,000,000 cubic feet of AAC, split 50/50 between blocks and wall panels, average densities of the products is 32 pounds per cubic foot (containing 61% fly ash), and sand and fly ash costs $40/ton and $6/ton, respectively (personal communication with Mr. Russ Miller, President of PAACA), then a savings of $995,520 per year can be expected from the replacement of sand with fly ash. Total savings for this plant (including ball mill installation and energy savings for grinding) would be over $2,120,000 in its first year of operation, and $1,220,000 each year thereafter.

OBJECTIVES

The objectives of this project were: 1) to prepare and perform pilot-scale production-test runs using fly ash from Illinois sources; 2) to assess the chemical, physical, and engineering properties of the products; 3) to conduct environmental suitability tests on the new products; and 4) to provide technical assistance to companies interested in building an AAC production plant in Illinois.

Since our industrial partner has their commercial facility shut down to resolve their business issues, our scale-up test runs were interrupted, therefore our efforts on this project were shift to the feasibility studies of AAC production using Illinois coal fly ashes from three new sources. In addition, extensive efforts were made to develop a process for the use of FBC ash in making AAC products. A total of more than fifty bench-scale runs have been conducted. The technical feasibility of the process was evaluated and the products' properties were analyzed. The results were favorable. Once our industry partner's commercial facility is available, conducting pilot-scale test runs is in order.

INTRODUCTION AND BACKGROUND

In Illinois, the three million tons of coal fly ash produced each year are typically ponded or landfilled, making fly ash a readily available raw material for making value-added products. This ISGS/UIUC study, in collaboration with Babb, aims at developing a process that uses Illinois coal fly ash for producing AAC products. Phase I (year 1) was completed, and during Phase II (year 2, this project) additional bench-scale tests on Illinois coal fly ashes from three new sources were conducted. In addition, extensive efforts were made to develop a process for the use of FBC ash in making AAC products. The results provided the industries involved with information to plan for pilot-scale and commercial-scale test runs.

EXPERIMENTAL PROCEDURES

Task 1. Sample Acquisition

Three fly ashes from Coffeen, Gibson, and Marion power plants in Illinois and one FBC ash from Marion power plant were collected in four 5-gallon buckets. Approximately 500 grams of each fly ash sample was ground and sieved through a 150 mesh sieve for chemical property characterizations in Task 2. However, for physical property characterizations in Task 2 and lab-scale production tests in Task 3, the fly ash samples were used with no extra treatment. Also, a survey for the evaluation of the availability of fly ash in terms of quality and sources was conducted.

Task 2. Characterization of Raw Materials, Intermediates, and Final Products

The content of major, minor, and trace elements, including mercury, and loss on ignition (LOI), in the raw materials, intermediates, and final products were determined. The elements were reported as either elemental or oxide concentrations. Analytical services were provided by the ISGS analytical laboratories and ALS CHEMEX laboratory in Canada. Both laboratories are equipped with an inductively coupled plasma (ICP) atomic emission spectrometer (AES) for determining 30 elements, X-ray fluorescence spectrometer (XRF) for metal oxide determinations, and cold vapor atomic absorption (AA) spectroscopy for mercury determination. Physical characteristics, including particle-size distributions and bulk densities of the fly ash samples, were determined as described in a previous report (Chou et al. 2003). For the engineering property tests, autoclaved and non-autoclaved AAC products were cut into suitable sizes. Compressive strength (a measure of the resistance of the concrete to axial loading, expressed as pounds per square inch (psi) of cross-sectional area) and porosity and density of the AAC products were determined using ASTM C 1386 (1998), and ASTM C 20 (2000), respectively.

Task 3. Bench-Scale AAC Production

Because our industrial partner has their commercial facility shut down to resolve their business issues, our efforts on scale-up test runs were used to conduct additional bench-scale tests on Illinois coal fly ashes from three new sources. In addition, extensive efforts were made to develop a process for the use of FBC ash in making AAC products. A total of more than fifty bench-scale runs have been conducted. The technical feasibility of the process was evaluated and the products' properties were analyzed.

Task 4. Economic Evaluation on Producing AAC Using Illinois Coal Fly Ash

An economic evaluation on producing AAC using Illinois coal fly ash was conducted based on a typical case with information provided by Babb and PAACA. The important factors to be considered included the number and type of AAC units produced each year by the specific plant studied, the amount of raw materials used, and the cost to produce those units plus the cost to transport the fly ash to the production facility. The added benefit of fly ash recycling and a lower energy requirement for production were estimated.

Task 5. Environmental Evaluation of AAC Products

A leaching study using simulated acid rainwater (U.S. EPA method 1320) was conducted on AAC products. The elements concentration (As, Ba, Cd, Cr, Hg, Ni, Se, and Pb) identified by the U.S. EPA in its toxicity list were determined. The synthetic acid rain water at pH = 3 was prepared according to EPA method 1320. For each duplicate extraction, ten grams of the solid sample was mixed with 200 mL (solid/liquid = 1:20) of the synthetic acid rain water in a 250 mL centrifuge bottle. The bottles containing the sample and acidified water were placed on a rotary agitator and the mixture was agitated for 24 hours at room temperature of approximately 23 - 24 C^o. The solids were then removed by centrifugation and the supernatant liquids filtered through a 0.45 micron Metricel membrane filter (GN-6). Aliquots of the liquids were acidified with nitric acid to pH <2 before being analyzed by inductively coupled plasma spectrometry.

Task 6. Technical and Management Reports

Eleven monthly reports and this final report were prepared and submitted to the ICCI.

RESULTS AND DISCUSSION

Sample Acquisition (Task 1)

Class F dry fly ash samples from Meredosia, Coffeen, Vermilion, Marion, Cayuga, and Gibson power plants were acquired, including also one FBC ash from Marion power plant. The source survey results (Table 1) show that there is enough fly ash supply for commercial AAC production. If a moderate size AAC plant was constructed which produced 3 million
cubic feet of AAC per year with a 1:1 ratio of blocks and wall panels and the products contained 60% fly ash and the average density of the AAC products were 30 and 40 lbs per cubic foot respectively, then this plant could use approximately 52,500 tons of fly ash each year. Based on the survey, the results showed that three of the power plants we have

studied could produce enough of fly ash to supply an AAC plant, and other three of the power plants also produce nearly enough of fly ash to supply an AAC plant.

Raw Material and AAC Product Characterization (Task 2)
Raw material - fly ash samples from six different sources were acquired and analysed for their chemical composition, including carbon content determined as loss on ignition (LOI). Among the samples analyzed, the dry fly ash from the Coffeen plant had the highest unburned carbon content with a LOI value as high as 12.9 wt%. See Table 2 for the results.

Table 1. Locations, power generation capacity, and quantities of fly ash produced by five power plants.

Power Plant Location	Capacity (MW)	Coal Source	Coal Consumed (Tons/year)	Fly Ash Generated (Tons/year)
Meredosia, IL	359	Illinois	700,000	45,000
Coffeen, IL	900	Illinois/Western	2,560,000	95,000
Vermilion, IL	175	Illinois	550,000	50,000
Marion, IL	280	Illinois	732,000	47,000
Cayuga, IN	1,062	Illinois/Indiana	3,100,000	225,000
Gibson, IN	3,250	Illinois/Indiana	9,000,000	700,000

Table 2. Metal oxides, sulfur content, and loss of ignition (LOI) of Class F coal fly ashes and FBC ash acquired.[1](All contents are expressed as weight %)

Fly Ash Samples	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	MgO
Meredosia DFA[2]	47.4	26.45	9.18	1.02	<0.05	1.06
Vermilion DFA	47.0	24.05	10.69	1.07	0.05	1.02
Coffeen DFA	45.8	21.42	6.67	1.23	<0.05	1.33
Marion DFA	46.9	18.96	16.69	1.20	0.05	1.12
Marion FBC	39.2	14.30	8.63	0.72	0.05	1.08
Cayuga DFA	50.0	25.97	10.38	1.28	0.04	1.01
Wehrhahn (2002)	>45	10 - 30	<10	NA[4]	NA	<2
Yutong (Wittmann, 1992)	>45	10 - 30	<10	NA	NA	<5
Silbet (Wittmann, 1992)	26 - 34	6 - 10	4 - 7	NA	NA	16 - 24

Fly Ash Samples	CaO	Na_2O	K_2O	P_2O_5	Cr_2O_5	S	LOI (%)
Meredosia DFA	4.71	1.26	2.30	0.19	0.02	0.51	5.04
Vermilion DFA	4.02	1.35	2.40	0.23	0.03	0.42	6.99
Coffeen DFA	4.39	2.04	2.80	0.25	0.01	0.58	12.90
Marion DFA	4.63	0.54	3.49	0.36	0.03	0.88	4.39
Marion FBC[3]	16.34	0.69	2.01	0.17	0.02	3.30	9.29
Cayuga DFA	2.53	1.02	2.54	0.14	0.02	0.29	3.65
Wehrhahn (2002)	<5	<2		NA	NA	<3	<5
Yutong (Wittmann, 1992)	<5	<5		NA	NA	<5	<10
Silbet (Wittmann, 1992)	16 - 24	2.5 – 3.5		NA	NA	3 - 6	NA

[1] Each value is a mean of duplicate analysis. [2] DFA = Dry fly ash. [3] FBC = Fluidized bed combustion ash.
[4] NA = Not available.

The data indicate that metal oxide compositions of Class F Illinois coal dry fly ash and fluidized bed combustion (FBC) ashes from Illinois coal, in general, met the basic requirements for AAC production as defined by the AAC producers, Wehrhahn (2002), Yutong (Wittmann, 1992), and Silbet (Wittmann, 1992), except that the LOI of Coffeen fly ash is higher than the 10 wt% defined by Yutong. Nevertheless, a LOI value of up to 12% is acceptable for AAC production according to the ASTM C 1452 (2000) specification. Also, in Asia and Europe fly ashes with LOIs of as much as 12% to 24% have been successfully used to produce AAC. The LOI values of the Illinois coal fly ashes (Table 2) ranged from 3.65 % to 12.9 %.

The SiO_2 and CaO contents of all the ash samples were close to the values recommended by the AAC producers, Wehrhahn (2002), Yutong (Wittmann, 2000), and Silbet (Wittmann, 1992) AAC producers. The SiO_2 content was >45% with the exception of a Marion FBC ash sample which had a 39.2% SiO_2. Similarly, the CaO was <5% except for the FBC ash sample that yielded 16.34%. The variations of SiO2, CaO, and LOI levels in Marion FBC ash did not cause problems during small-scale AAC production tests. In Russia, Silbet also had successfully used FBC ash to manufacturing AAC products (Wittmann, 1992).

Particle size distributions on the collected coal fly ash samples were determined by the Laboratory Services Group. Approximately 97% of the Meredosia, Vermilion, Cayuga, and 89% of Coffeen fly ash particles were smaller than 88 micrometers, and approximately64-78% and 57% of the particles in the same fly ashes were smaller than 22 micrometers (Table 3).

Environmental study - Fly ash is not among the solid wastes currently being regulated by the U.S. EPA. However, the concentrations of heavy metals in these fly ashes were determined. As indicated in Table 4, the concentrations of boron (B) and zinc (Zn) were high in most fly ashes, especially Coffeen dry fly ash. The mercury concentrations of the ash samples ranged from 0.01 to 0.28 ppm (mg/kg). The leaching characteristics of the fly ash samples were also examined. Table 5 lists the concentrations of the same elements listed in Table 4 found in the extracts of the fly ash samples and the regulatory thresholds set by the U.S. EPA. The concentrations of seven heavy elements in all the extracts were below the limits set by the U.S. EPA for other solid waste materials. The results indicate that the fly ash samples may be considered environmentally safe raw materials.

The major elements of environmental concern in air dried and autoclaved fly ash AAC products such as As, B, Cd, Co, Cr, Hg, Li, Ni, Pb, and Zn were also determined. The concentrations of most elements in Class F fly ash AAC blocks increased after autoclaving, except for the FBC ash AAC blocks, which remained approximately the same (Table 6).

The mercury concentration in most of the AAC products showed no significant change except in the Vermilion AAC blocks in which the mercury concentration decreased from 0.04 ppm to 0.01 ppm after being autoclaved (Table 6). In our previous studies, the results indicated that the metal ion concentrations of the autoclaved and non-autoclaved AAC extracts were very low, and no detectable mercury concentrations were found in the steam water (Chou et al., 2003). The concentrations of S in air dried and autoclaved AAC products are not significantly different; we expect that no secondary S emission problem will occur during the production of fly ash AAC products. The results indicate that the fly ash AAC products may be considered environmentally safe building materials.

Table 3. Particle size distributions of Illinois coal fly ash samples collected from various electrical power plants (size in micrometers).

Particle size	Meredosia		Coffeen		Vermilion		Cayuga	
	% Pass	% Change	% Pass	% Change	% Pass	% Change	% Pass	% Change
497.8	100.00	0.00	100.00	1.41	100.00	0.00	100.00	0.00
352.0	100.00	0.00	98.59	2.41	100.00	0.00	100.00	0.00
248.9	100.00	0.00	96.18	2.26	100.00	0.00	100.00	0.00
176.0	100.00	0.82	93.92	2.47	100.00	0.00	100.00	0.00
124.5	99.18	1.66	91.45	3.54	100.00	0.92	100.00	0.26
88.00	97.52	4.04	87.91	5.29	99.08	4.56	99.74	2.46
62.23	93.48	8.04	82.62	7.00	94.52	9.87	97.28	5.25
44.00	85.44	10.06	75.62	8.16	84.65	10.86	92.03	6.48
31.11	75.38	9.73	67.46	9.54	73.79	9.61	85.55	7.56
22.00	65.65	9.22	57.92	10.38	64.18	9.28	77.99	8.41
15.56	56.43	8.89	47.54	9.02	54.90	8.85	69.58	8.90
11.00	47.54	9.03	38.52	7.56	46.05	8.54	60.68	9.97
7.778	38.51	8.38	30.96	6.22	37.51	7.88	50.71	10.28
5.500	30.13	6.65	24.74	4.64	29.63	6.33	40.43	8.73
3.889	23.48	5.41	20.10	3.71	23.30	5.12	31.70	7.13
2.750	18.07	4.74	16.39	3.54	18.18	4.51	24.57	6.07
1.945	13.33	4.41	12.85	3.99	13.67	4.51	18.50	5.96
1.375	8.92	3.77	8.86	4.04	9.16	4.24	12.54	5.70
0.972	5.15	2.44	4.82	2.71	4.92	2.76	6.84	3.73
0.688	2.71	1.40	2.11	1.38	2.16	1.40	3.11	1.86
0.486	1.31	0.92	0.73	0.73	0.76	0.76	1.25	1.00
0.344	0.39	0.39	1.00	0.00	0.00	0.00	0.25	0.25
0.243	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Physical properties – Tests on additional fly ash samples were conducted to improve AAC cake formation. A range of formulations (CaO/SiO_2 ratio) were developed to produce AAC with excellent cell structure and physical properties. The preliminary results using a new formulation indicated that FBC ash can be used to produce acceptable AAC products. Some of the physical properties of the AAC blocks made from the Meredosia, Vermilion, Cayuga, Gibson, and Marion Class F fly ashes and Marion FBC ash compared with regular sand AAC blocks are shown in Table 7. Laboratory-scale AAC blocks were cured at 174 psi, 375^o F, for 12 hours. The compressive strength of the AAC blocks thus produced ranged from 245 to 675 psi. In most cases the data are within the range (350-435 psi) of compressive strengths for commercially accepted AAC. The compressive strength value of the FBC AAC block was relatively low, but with some modification of the formulations the compressive strength was increased from 245 psi to 452 psi. In most cases, the AAC blocks produced from the fly ashes listed in Table 6 were comparable to Babb's commercialfly ash AAC blocks with a density of approximately 41 lbs/ft^3 and a porosity of 65% (Chou et al., 2003).

Table 4. Element concentrations in dry Illinois coal combustion fly ashes and fluidized bed combustion ash.

Fly Ash Samples	Element Concentrations (ppm, mg/Kg, * Except where specified as a %)							
	As	**B**	**Ba**	**Ca***	**Cd**	**Cr**	**Li**	**Ni**
Meredosia DFA	94.9	1230	120	2.36	2.66	43	18.4	95.7
Vermilion DFA	84.2	970	370	3.11	1.84	52	44.4	58.3
Coffeen DFA	117.0	1916	451	3.05	7.10	212	93.0	548.0
Marion DFA	120.5	760	140	2.40	17.5	155	26.8	68.9
Marion FBC	33.0	330	160	10.4	3.40	44	44.9	54.2
Cayuga DFA	101.5	700	90	1.42	1.67	52	23.1	92.0

Fly Ash Samples	Element Concentrations (ppm, mg/Kg, * Except where specified as a %)							
	Pb	**K***	**Na***	**Mg***	**Mn**	**S***	**Zn**	**Hg**
Meredosia DFA	48.0	0.31	0.14	0.16	166	0.51	345	0.04
Vermilion DFA	86.6	0.28	0.20	0.16	426	0.42	466	0.08
Coffeen DFA	186.0	2.36	1.32	0.76	278	0.58	1042	0.04
Marion DFA	189.0	0.65	0.11	0.20	158	0.82	1210	0.01
Marion FBC	83.2	0.96	0.18	0.46	308	3.61	307	0.28
Cayuga DFA	55.6	0.24	0.12	0.13	212	0.29	207	0.04

Table 5. Element concentrations in simulated acid rain extracts after raw materials were agitated with acidified water for 24 hours.

Fly Ash Samples	Element Concentrations in extracts (solid : liquid = 1 : 20) (mg/L)							
	As	**B**	**Ba**	**Ca**	**Cd**	**Cr**	**Li**	**Ni**
Meredosia DFA	<0.2	38.40	0.24	709	<0.01	0.41	0.20	<0.01
Vermilion DFA	<0.2	18.20	0.13	186	<0.01	0.16	0.56	<0.01
Coffeen DFA	<0.2	59.82	0.29	345	0.01	0.64	0.91	0.02
Marion DFA	<0.2	15.65	0.21	265	0.02	0.45	0.24	<0.01
Marion FBC	<0.2	7.80	0.23	998	0.01	0.18	0.66	<0.01
Cayuga DFA	<0.2	15.40	0.19	226	<0.01	0.12	0.34	<0.01
U.S. EPA limit	5	N/A	100	N/A	1.00	5.00	N/A	5.00

Fly Ash Samples	Element Concentrations in extracts (solid : liquid = 1 : 20) (mg/L)							
	Pb	**K**	**Na**	**Mg**	**Mn**	**S**	**Zn**	**Hg**
Meredosia DFA	<0.05	<2.0	40.9	0.02	<0.03	93.4	0.04	<0.00002
Vermilion DFA	<0.05	14.0	48.9	0.06	<0.03	94.0	<0.01	<0.00002
Coffeen DFA	0.05	29.5	79.6	0.09	<0.03	95.7	0.06	<0.00002
Marion DFA	0.05	18.6	35.7	0.07	<0.03	98.1	0.07	<0.00002
Marion FBC	<0.05	20.2	38.6	0.08	<0.03	365.0	0.05	<0.00002
Cayuga DFA	<0.05	13.0	0.12	0.02	<0.03	95.7	<0.01	<0.00002
U.S. EPA limit	5.00	N/A	N/A	N/A	N/A	N/A	N/A	0.2

The preliminary results indicate that with the proper adjustment of the CaO/SiO_2 ratio and sand addition, FBC ash also can be used for AAC production. Compressive strength and density also can be influenced by the lime/cement ratio (Ramamurthy and Narayanan, 2000). Although both the curing time and the curing pressure affect the strength, the autoclaved aerated concrete) is typically classified according to its compressive strength, strength is more dependent on the curing temperature than the curing time. PAAC (precast which ranges from about 250 to 1000 psi and correspond to oven-dry weights ranging from 25 to 50 lbs/ft^3 (NPCA, 2000).

Table 6. The major environmentally concerned elements in air dried and autoclaved fly

ash AAC samples (mg/Kg or weight %).

Sample	Treatment	Element concentrations (mg/Kg or weight %)					
		As	B	Cd	Co	Cr	Hg
Meredosia AAC	Air dried	60	870	1.96	16.1	55	0.01
Meredosia AAC	Autoclaved	61	950	2.95	25.8	60	<0.01
Vermilion AAC	Air dried	55	690	1.32	14.7	61	0.04
Vermilion AAC	Autoclaved	48	730	1.99	22.2	68	0.01
Marion AAC	Air dried	89	520	12.05	14.0	124	<0.01
Marion AAC	Autoclaved	83	600	13.70	21.3	140	0.01
Marion FBC AAC	Air dried	23	230	2.62	13.8	61	0.07
Marion FBC AAC	Autoclaved	20	230	2.49	13.6	61	0.08

Sample	Treatment	Element concentrations (mg/Kg or weight %)					
		Li	Ni	Pb	Se	Zn	S (%)
Meredosia AAC	Air dried	21.2	73.4	36.3	4.4	342	0.60
Meredosia AAC	Autoclaved	51.8	124.0	74.6	3.8	583	0.58
Vermilion AAC	Air dried	39.7	45.5	60.5	2.3	426	0.48
Vermilion AAC	Autoclaved	107.0	70.9	130.0	2.3	690	0.51
Marion AAC	Air dried	25.8	59.7	131.5	3.8	927	0.81
Marion AAC	Autoclaved	51.1	93.8	222.0	3.7	1535	0.81
Marion FBC AAC	Air dried	47.3	46.6	64.5	4.1	341	2.17
Marion FBC AAC	Autoclaved	46.4	45.2	62.4	3.8	326	2.21

AAC = AAC blocks contained 68% Class F fly ashes or fluidized bed combustion (FBC) ash.

Table 7. Physical properties of AAC blocks produced with Illinois coal fly ashes, FBC ash, and regular sand AAC blocks – A preliminary comparison.

Raw Material (Wt %)	% Moisture Content	% Porosity	Density (lbs/ft^3)	Compressive strength (Psi)
Meredosia DFA (64%)	8.45	69.4	40.05	675
Coffeen DFA (62%)	9.16	75.5	39.34	611
Vermilion DFA (64%)	7.88	67.4	42.85	589
Cayuga DFA (64%)	8.15	64.8	41.65	615
Marion DFA (64%)	8.65	59.8	40.31	545
Marion DFA (62%)	8.98	61.2	41.13	550
Marion Mix* (64%)	9.11	62.5	39.25	452
Marion FBC (64%)	8.77	65.9	39.33	245
Marion FBC (56%)	8.95	67.2	38.85	410
Commercial Sand (70%)	NA	70 - 80	25 - 50	250 - 1000

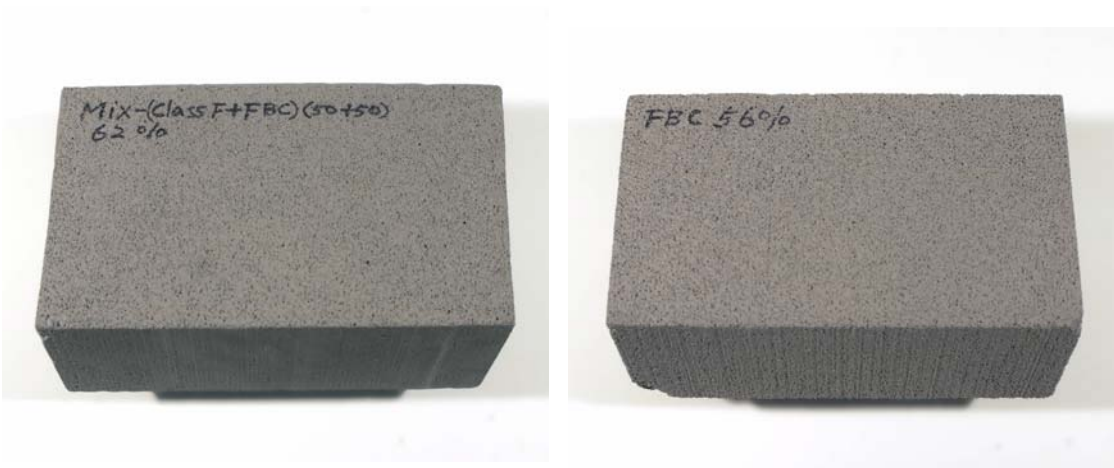
* Mix = Marion Class F fly ash/FBC ash (50/50) mixture

<u>Bench-Scale AAC Blocks Production (Task 3)</u>

Conducting pilot-scale test runs at Babb's Adel plant was originally proposed, but it was delayed. This is because the plant was shut down due to Babb's business difficulty. While we were waiting for Babb to make their plant facility available to us, additional bench-scale screening tests on Illinois coal fly ashes of three new sources were conducted. In addition, an extended effort was made to develop a process for the use of FBC ash.

AAC blocks with dimensions 7" x 10" x 6" were made with several formulations of fly ash, lime, and Portland type I cement. Ground silica sand (provided by the U.S. Silica Sand Company) was added to some mixtures. AAC blocks containing 56-68% fly ash and FBC Ash with various amount of lime, cement, and aluminium powder were successfully produced. Representative AAC blocks made from Marion's FBC ash are shown in Figure 1.

As indicated in Table 7, most of the AAC blocks produced possess good compressive strengths, except the AAC block made from FBC ash without modification of the formulation was less desirable. However, the quality of the FBC AAC blocks can be improved by adding silica sand or mixing with Class F fly ash. The compressive strengths of FBC blocks increased from a marginal 245 psi to 410-452 psi in the modified formulations.



(A) (B)

Figure 1. AAC block made from 62-wt% of Class F and FBC ash (50/50) (A) and 56-wt% of FBC ash (B).

Economic Evaluation on Producing AAC Using Illinois Coal Fly Ash (Task 4)

An economic evaluation on producing AAC using Illinois coal fly ash was conducted based on a typical case with information provided by Babb and PAACA. During the production of AAC with fly ash, the major steps of the process are the same as those of the process with sand with the exception of grinding.

Production cost - When sand is replaced by fly ash for making AAC, no grinding is required. For a specific production plant, a 500 HP ball mill sand grinder has a yearly

operating cost on the order of $225,000, assuming standard electrical, manpower, and maintenance costs. The installed cost of a new ball mill is estimated at $900,000.
Raw material cost – At a production rate of 3,000,000 ft^3/year of AAC, and split between 50/50 of blocks and wall panels, assuming the average density of the products is 32 lbs/ ft^3 (Containing 61% fly ash), and sand and fly ash cost $40/ton and $6/ton, respectively (personal communication with Mr. Russ Miller, President of PAACA), then a saving of $995,520/year can be expected from the replacement of sand with fly ash.

Total savings – A new AAC facility using fly ash to produce 3,000,000 cubic feet of AAC materials per year would result in a savings of over $2,120,000 in its first year of operation over new AAC production facility and $1,220,000 each year thereafter.

<u>Environmental Evaluation of Raw Materials and AAC Products (Task 5)</u>
The leaching characteristics of the fly ash samples were examined. Table 5 lists the concentrations of the same elements listed in Table 4 and found in the extracts of fly ash samples as well as the regulatory thresholds set by the U.S. EPA. The concentrations of seven heavy elements (As, Ba, Cd, Cr, Ni, Pb, and Hg) in all the extracts were below the limits set by the U.S. EPA for other solid waste materials.

The test results indicate that the fly ash samples tested may be considered environmentally safe raw materials. Similar leaching test results of the AAC products were reported in a previous report (Chou et al., 2003).

<u>Technical and Management Reports (Task 6)</u>
Eleven monthly reports and this final report were prepared and submitted to the ICCI.

CONCLUSIONS AND RECOMMENDATIONS

From a survey of fly ash sources, we find there is enough fly ash supply in Illinois for commercial AAC production. All fly ashes tested were acceptable for use in the production of AAC blocks at a lower density. For higher density AAC panel production, the addition of milled sand or a fibre additive will be necessary. AAC blocks containing 56-60% by weight of Illinois coal FBC ash balanced with various amounts of lime, silica sand, cement, and aluminium powder were successfully produced. The AAC blocks produced showed good physical properties. Also, the AAC blocks produced with dry Illinois coal fly ashes appear to be environmentally acceptable.

Continued work (2004-2005) on pilot-scale production test runs on available Illinois coal fly ashes and FBC ashes is being considered for funding by the DCEO/ICCI. Four to five dry Illinois coal fly ashes and FBC ashes that have been tested will be selected for pilot-scale production demonstration. The selection of fly ash sources will be based on the geographic location, quality and availability of fly ash sources and incorporating a part of the AAC industry that is willing to build an AAC plant in Illinois.

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DISCLAIMER STATEMENT

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Principal Investigator:	S. F. J. Chou, Illinois State Geological Survey (ISGS)
Other Investigators:	M. I. M. Chou (ISGS) and J. M. Bukowski, University of Illinois (UIUC)
Project Manager:	Francois Botha, Illinois Clean Coal Institute

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None

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List of Equipment Purchased

Acct. #	Date Acquired	Short Description	Cost	Tag#	Bldg. & Rm. #
598068	January, 2004	Thermo Haake Visco Tester 7L (measure slurry density)	$1,850	E01634	NRB Rm. 334