TECHNICAL REPORT

September 1 through November 30, 1994

**Project Title: A FIELD DEMONSTRATION PROJECT UTILIZING FBC/PCC
RESIDUES FOR PAVING MATERIALS**

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ABSTRACT

In the past two years, Southern Illinois University at Carbondale (SIUC), under the sponsorship of Illinois Clean Coal Institute, has performed a series of laboratory research into engineering properties of roller compacted concretes containing fluidized bed combustion/pulverized coal combustion (FBC/PCC) by-products as well as FBC/PCC-Portland Cement concrete mixtures prepared using conventional placement technique. This laboratory effort has resulted in identification of a number of potentially viable commercial applications for the FBC by-products residues derived from Illinois high-sulfur coal.

One potential and promising application of the FBC/PCC solid waste residues, which also accounts for the large utilization of coal-based by-product materials, is in pavement construction. The proposal presented herein is intended to embark into a new endeavor in order to bring the commercialization aspect of the initial laboratory project a step closer to reality by conducting a field demonstration of the optimized mixtures identified during the two-year laboratory investigation. A total of twenty-three different pavement slabs will be constructed at an identified site located in the Illinois Coal Development Park, Carterville, Illinois, by two construction contractors who are part of the industrial participants of the initial project and have expressed interest in the construction of experimental slabs. Both conventional and roller compacted concrete placement techniques will be utilized. All sections will be subjected to an extensive engineering evaluation and will be monitored for nearly a year for both short and long-term performance. The field results will be compared to that of the equivalent laboratory-prepared mixes in order to ascertain the suitability of the proposed mixes for field application.

During this reporting period, the physico-chemical and preconditioning characteristics of the raw materials were evaluated. Construction of the experimental road consisting of twenty-three surface and base course slab sections was also completed.

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EXECUTIVE SUMMARY

The Status of the major tasks are reported below.

The Physico-Chemical Characteristics of Raw Materials

The matrix constituents used in the preparation of the field paving slabs included FBC spent bed, PCC class F fly ash, natural fine and coarse aggregates, type V portland cement, and water.

The PCC fly ash, used as a main cementitious constituent, was supplied by American Fly Ash Company of Naperville, Illinois. The chemical and physical properties are shown in Table 1 and 2, respectively. Based on the requirements of ASTM C618, this by-product residue can be classified as class F fly ash. It had a specific gravity of 2.39. The #325 sieve fineness, autoclave expansion, water requirement, and seven-day compressive strength were all within the required limits of the specifications for use of fly ash in concrete.

The type V portland cement, used as a complementary cementitious material, was shipped by Lone Star Industries, Inc., of Cape Girardeau, Missouri. Its chemical and physical properties are reported in Table 3 and 4, respectively. This high sulfate-resistant portland cement had a Tricalcium Aluminate content (C_3A) of 0.17%.

The FBC spent bed was obtained from Archer Daniel Midland in Decatur, Illinois. The chemical compositions of the preconditioned FBC spent bed are reported in Table 1. As expected, a small quantity of pozzolun oxides, calcium oxide, and sulfur trioxide were found in the FBC by-product residues. In an attempt to convert the unreacted lime (CaO) and anhydrite calcium sulfate ($CaSO_4$) into calcium hyroxide ($Ca(OH)_2$) and sulfate-dihydrate ($CaSO_4 \cdot 2H_2O$), respectively, the FBC spent bed was preconditioned by 12.5% water addition prior to use. The two adopted testing methods, namely: peak temperature and thermogravimetric analysis, confirmed the optimum hydration at the above-mentioned level of water addition. No agglomeration and/or cementation resulted. The pH level of the FBC spent bed was found to be 11.98, indicating a passive environment if steel reinforcements are used.

The oven-dry (OD) and saturated surface dry(SSD) specific gravity of the FBC spent bed, as reported in Table 5, were 2.08 and 2.38, respectively. The large difference between the two specific gravities indicates that the FBC spent bed can absorb a large amount of water (the actual absorption was 14.60%). No organic impurities in the FBC spent bed were found. Its particle size distribution, as shown in Table 6, indicates a low fineness modules value of 1.8.

In an attempt to enhance the size gradation of the fine component of the matrix, a silicious natural fine aggregate, obtained from a quarry in southern Illinois, was used. The particle size, as shown in Table 6, was mostly within the aggregate grading recommended by ASTM C33. The fineness modules indicated a value of 2.8. The oven-dry and saturated surface dry

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specific gravity, and absorption are shown in Table 7. Tests on organic impurities failed to indicate the presence of any organic matters in the natural fine aggregate.

The limestone coarse aggregate was obtained from a quarry in southern Illinois. Its particle distribution was within the grading requirements of size number 56 recommended by ASTM C33 (maximum particle size of an inch). The remaining physical properties of the coarse aggregate are described in Table 8.

Tap water conforming with the requirements of ACI 301 was used during the blending of the concrete mixtures.

Mixture Design Details

Based on the laboratory results of prior investigation, a total of eleven and six matrix proportions were selected for the fabrication of surface and base course roller compacted slabs, respectively. For the vibratory placement of concrete sections, three base and three surface course mixture proportions were adopted.

Slab Sections

Each slab was approximately 6 feet wide and 12 feet long. The final thickness of the surface and base course sections were 8 inches and 6 inches, respectively. Appropriate control joints were provided. However, for the purpose of this investigation, no load transfer devices were utilized.

Construction of the Experimental Slabs

An existing 300 feet long road site located in the Illinois Coal Development Park was used to construct the surface and base course experimental sections. Both conventional (Vibratory) and roller compacted concrete placement techniques were utilized. The subgrade was graded and then compacted using sheepsfoot and steel rollers.

In the absence of a pugmill mixer, blending and mixing was done using a conventional vibratory concrete mixer. It is noted that for zero-slump mixtures (roller compacted concrete), the drum mixer increases the tendency of balling of the fine constituents which may consequently prevent the proper dispersion of the cementitious components of matrix, resulting in the strength reduction of the hardened product. The following mixing procedures was adopted for the preparation of the conventional concrete matrices:

- 1) The preweighed natural coarse and fine aggregates were first blended with one-third of the required mixing water for a period of 3 minutes. Next, the measured FBC spent bed, PCC fly ash and portland cement (if any) were added and mixing continued for another three minutes. Finally, the remaining two-third of the required water was poured into the moving drum and mixing continued for additional three minutes or until a homogenous matrix was obtained.

- 2) The consistency of the fresh concrete mixtures was evaluated through a slump test. The obtained values were between $4(\pm \frac{1}{4})$ and $5\frac{1}{4}(\pm \frac{1}{4})$ inches.

In an attempt to reduce tendency to balling of the zero-slump matrices, a different mixing procedure was adopted for the roller compacted concrete mixtures. The FBC spent bed and natural fine aggregate (if any) were first dry-mixed for a period of three minutes. The cementitious component of the matrix, PCC fly ash and portland cement (if any), and one-third of the required mixing water were then added and mixing continued for another three minutes. Finally, the preweighed coarse aggregate and the remaining water were added until a uniform blended mixture was attained.

After blending, the mixes were transported, using truck mixers, to the construction site at a location in the Illinois Coal Development Park, Carterville. For the conventional concrete mixtures, fresh matrices were placed and spread in the appropriate forms, and then consolidated using an internal vibrator. Immediately after densification process, spreading and bull floating were conducted. The final surface finish was accomplished using a hand trowel. A broom was used to retain rough scoring impression on concrete slabs.

In the case of roller compacted concrete mixtures, the 10 inches and 8 inches, of loose zero-slump fresh matrix (for surface and base course sections, respectively) was compacted into 8 and 6 inches final thickness, in two lifts, using a hand compactor and a self-propelled steel vibratory roller. No additional surface finish treatments were used.

After concrete slabs were placed and finished, a coat of chemical sealant was spread on the slab surface to maintain sufficient moisture in the mixture for the hydration of cementitious binders. In addition, a plastic sheet was used to cover the test sections during the entire curing period.

Table 1: Chemical Test Data of Hydrated FBC Spent Bed and PCC Fly Ash

Chemical Composition	"FBC" Spent Bed	"PCC" Fly Ash	Fly Ash Specifications (ASTM C618)
Silicon Oxide (SiO_2)	12.60	53.40	----
Aluminum Oxide (Al_2O_3)	4.03	23.10	----
Iron Oxide (Fe_2O_3)	2.31	12.70	----
Total ($SiO_2 + Al_2O_3 + Fe_2O_3$)	18.94	89.20	50.0 Minimum, Class C 70.0 Minimum, Class F
Sulfur Trioxide (SO_3)	20.47	0.69	50.0 Maximum
Calcium Oxide (CaO)	49.70	1.65	Less than 10%, Class F More than 10%, Class C
Magnesium Oxide (MgO)	2.71	0.92	----
Loss on Ignition	0.47	0.98	6.0 Maximum
Free Moisture	0.39	0.24	3.0 Maximum
Water of Hydration	7.11	0.0	----
Total Na_2O	0.23	0.67	----
Available Alkalies as Na_2O	N/A	2.26	1.5 Maximum
Total K_2O	0.25	2.41	----
Others ($TiO_2 + P_2O_5 + SrO + BaO$)	0.12	3.48	----
pH	11.98	4.53	----

Table 2: Physical Properties of PCC Fly Ash

#325 Sieve Fineness		Specific Gravity	Autoclaved Expansion		Water Requirement		7-Day Compressive Strength*		
Actual	Limit		Actual	Limit			Actual	ASTM	AASHTO
22.60	Max. 34%	2.39	0.03	0.80%	93.30	Max. 105	85.40	Min. 75%	Min. 60%

* As percentage of reference mixture

Table 3: Chemical Compositions of Portland Cement

Type Portland Cement Chemical Compositions	Test Results (%)	Standard Requirements (ASTM C150)
Silicon Dioxide (SiO ₂)	22.64	N.A.
Aluminum Oxide (Al ₂ O ₃)	3.22	N.A.
Ferric Oxide (Fe ₂ O ₃)	4.98	N.A.
Carbon Oxide (CaO)	62.45	N.A.
Magnesium Oxide (MgO)	3.15	Maximum 6.0%
Sulfur Trioxide (SO ₃)	2.10	3.0%
Loss on Ignition	0.51	Maximum 3.0%
Tricalcium Silicate (C ₃ S)	47.43	N.A.
Tricalcium Aluminate (C ₃ A)	0.11	N.A.
Insoluble Residue	0.17	Maximum 0.75%
Total Alkalies	0.54	Maximum 0.60%

Table 4: Physical Properties of Portland Cement

Type Portland Cement Physical Tests	Test Results	Standard Requirements (ASTM C150)
Compressive Strength: 1 day 3 days 7 days 28 days 56 days 90 days	850 psi 1720 psi 2400 psi 4780 psi 5910 psi 6390 psi	N.A. Minimum 1200 psi Minimum 2200 psi 3000 psi N.A. N.A.
Surface Area (Fineness): Blaine	3060 cm ² /g	Minimum 2800 cm ² /g
Setting Time: Vicat Initial Vicat Final	170 min. 330 min.	Minimum 45 min. Maximum 375 min.
Autoclave Expansion Air Content of Mortar	0.05% 8.4 %	Maximum 0.80% Maximum 12.0%

Table 5: Physical Properties of FBC Spent Bed

Fineness Modulus	Specific Gravity - OD	Specific Gravity - SSD	Absorption (%)	Organic Impurities
1.80	2.08	2.39	14.60	1, None

Table 6: Size Distribution of Fine Aggregates

Aggregate Type	Grain Size Distribution, Percent Passing Sieve Size (mm)						
	4.75	2.36	1.18	0.6	0.30	0.15	
FBC Spent Bed	100	98.92	96.02	82.22	40.52	8.78	4.68
Natural Fine Aggregate	100	95	80	35	5	2	0.18
Upper Limit ASTM C33	100	100	85	60	30	10	-
Lower Limit ASTM C33	95	80	50	25	10	2	-

Table 7: Physical Characteristics of Silicious Fine Aggregate

Fineness Modulus	Specific Gravity - OD	Specific Gravity - SSD	Absorption (%)	Organic Impurities
2.80	2.65	2.66	0.50	1, None

Table 8: Physical Properties of Limestone Coarse Aggregate

Maximum Size (Max. Normal Size)	Specific Gravity - OD	Specific Gravity - SSD	Absorption (%)	Rodded Unit Weight - OD (lb/ft ³)	Rodded Unit Weight - SSD (lb/ft ³)	Void Ratio
1 (3/4)	2.64	2.67	0.75	93.50	94.20	43.75

OBJECTIVES

This research investigation and its assigned tasks is designed to ascertain the constructability and performance of cement and non-cement concrete mixtures, identified during the two-year laboratory investigation using vibratory and roller compacted techniques, under realistic climatic and traffic flow of field conditions. A total of twenty-three matrix proportions is considered for field slabs, each 6x12 ft. in size. After construction, the two major tasks, field monitoring and laboratory testing of the cored samples, are used to evaluate the hardened characteristics and serviceability of the trial mixtures. Cored samples will be tested for strength, strength development, stiffness and deformation shrinkage/expansion, and long-term performance under abrasive action of traffic and freezing and thawing of winter climates. The results of the field and laboratory made samples are compared in order to identify the proper correlations between them.

During this reporting period, the physico-chemical and preconditioning characteristics of the raw materials were evaluated. Construction of the experimental road consisting of twenty-three surface and base course slab sections was also completed.

INTRODUCTION AND BACKGROUND

In an attempt to reduce the potential hazards of acid rain and enhance the quality of life in the State of Illinois, coal-fired plants burning high-sulfur Illinois Coal are adopting fluidized bed combustion (FBC) process. FBC results in the production of large quantities of by-product wastes which have different physico-chemical characteristics than those generated by the conventional coal-burning processes. While the two-year laboratory investigation has provided valuable scientific data on the performance of various FBC/PCC cement and non-cement mixtures and identified a number of potentially viable construction-related applications, field feasibility studies are needed to bring the laboratory investigation a step closer to reality. It is, therefore, the thrust of this research project to evaluate the constructability and performance of field experimental slabs utilizing FBC spent bed as a filler aggregate and PCC fly ash as a main cementitious constituent of concrete matrix. Cored samples of hardened concretes will be tested for a variety of mechanical properties and long-term performance under different climatic conditions and ages.

In summary, this investigation has a dual purpose aimed at enhancing the economic and industrial well-being of the state by developing a cost-effective construction materials while using by-product wastes which will otherwise end up landfill causing adverse environmental and economical problems.

EXPERIMENTAL PROCEDURE

The chemical properties of the FBC spent bed were obtained using ASTM C311. The physical properties of the FBC spent bed, and natural fine and coarse aggregates were determined using ASTM C33, C128, and C40. the physico-chemical characteristics of the PCC fly ash were conducted using ASTM C311.

CONSTRUCTION OF THE EXPERIMENTAL SLAB

Mixture Design Details

Based on the laboratory results of prior investigation, a total of eleven and six matrix proportions were selected for the fabrication of surface and base course roller compacted slabs, respectively. Table 9 details the matrix proportion for the FBC/PCC roller compacted concrete mixtures. For the vibratory placement of concrete sections, three base and three surface course mixture proportions, as documented in Table 10, were adopted.

Slab Sections

Each slab was approximately 6 feet wide and 12 feet long. The final thickness of the surface and base course sections were 8 inches and 6 inches, respectively. Appropriate control joints were provided. However, for the purpose of this investigation, no load transfer devices were utilized.

Field Construction

An existing 300 feet long road site located in the Illinois Coal Development Park was used to construct the surface and base course experimental sections. Both conventional (Vibratory) and roller compacted concrete placement techniques were utilized. The subgrade was graded and then compacted using sheepsfoot and steel rollers.

In the absence of a pugmill mixer, blending and mixing was done using a conventional vibratory concrete mixer. It is noted that for zero-slump mixtures (roller compacted concrete), the drum mixer increases the tendency of balling of the fine constituents which may consequently prevent the proper dispersion of the cementitious components of matrix, resulting in the strength reduction of the hardened product. The following mixing procedures was adopted for the preparation of the conventional concrete matrices:

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- 2) The consistency of the fresh concrete mixtures was evaluated through a slump test. The obtained values were between $4(\pm \frac{1}{4})$ and $5\frac{1}{4}(\pm \frac{1}{4})$ inches.

In an attempt to reduce tendency to balling of the zero-slump matrices, a different mixing procedure was adopted for the roller compacted concrete mixtures. The FBC spent bed and natural fine aggregate (if any) were first dry-mixed for a period of three minutes. The cementitious component of the matrix, PCC fly ash and portland cement (if any), and one-third of the required mixing water were then added and mixing continued for another three minutes. Finally, the preweighed coarse aggregate and the remaining water were added until a uniform blended mixture was attained.

After blending, the mixes were transported, using truck mixers, to the construction site at a location in the Illinois Coal Development Park, Carterville. For the conventional concrete mixtures, fresh matrices were placed and spread in the appropriate forms, and then consolidated using an internal vibrator. Immediately after densification process, spreading and bull floating were conducted. The final surface finish was accomplished using a hand trowel. A broom was used to retain rough scoring impression on concrete slabs.

In the case of roller compacted concrete mixtures, the 10 inches and 8 inches, of loose zero-slump fresh matrix (for surface and base course sections, respectively) was compacted into 8 and 6 inches final thickness, in two lifts, using a hand compactor and a self-propelled steel vibratory roller. No additional surface finish treatments were used.

After concrete slabs were placed and finished, a coat of chemical sealant was spread on the slab surface to maintain sufficient moisture in the mixture for the hydration of cementitious binders. In addition, a plastic sheet was used to cover the test sections during the entire curing period.

RESULTS AND DISCUSSION

The matrix constituents used in the preparation of the field paving slabs included FBC spent bed, PCC class F fly ash, natural fine and coarse aggregate, type V portland cement, and water.

The PCC fly ash, used as a main cementitious constituent, was supplied by the American Fly Ash Company of Naperville, Illinois. The chemical and physical properties are shown in Table 1 and 2 of the Technical Report, respectively. Based on the requirements of ASTM C618, this by-product residue can be classified as class F fly ash. It had a specific gravity of 2.39. The #325 sieve fineness, autoclave expansion, water requirement, and seven-day compressive strength were all within the required limits of the specifications for use of fly ash in concrete.

The type V portland cement, used as a complementary cementitious material, was shipped by Lone Star Industries, Inc., of Cape Girardeau, Missouri. Its chemical and physical properties are reported in Table 3 and 4 of the Technical Report, respectively. This high sulfate-resistant Portland Cement had a Tricalcium Aluminate content (C_3A) of 0.17%.

The FBC spent bed was obtained from Archer Daniel Midland in Decatur, Illinois. The chemical compositions of the preconditioned FBC spent bed are reported in Table 1 of the Technical Report. As expected, a small quantity of pozzolun oxides, calcium oxide, and sulfur trioxide were found in the FBC by-product residues. In an attempt to convert the unreacted lime (CaO) and anhyrite calcium sulfate ($CaSO_4$) into calcium hyoxide ($Ca(OH)_2$) and sulfate-dihydrate ($CaSO_4 \cdot 2H_2O$), respectively, the FBC spent bed was preconditioned by 12.5% water addition prior to use. The two adopted testing methods, namely: peak temperature and thermogravimetric analysis, confirmed the optimum hydration at the above-mentioned level of water addition. No agglomeration and/or cementation resulted. The pH level of the FBC spent bed was found to be 11.98, indicating a passive environment if steel reinforcements are used.

The oven-dry (OD) and saturated surface dry(SSD) specific gravity of the FBC spent bed, as reported in Table 5 of the Technical Report, were 2.08 and 2.38, respectively. The large difference between the two specific gravities indicates that the FBC spent bed can absorb a large amount of water (the actual absorption was 14.60%). No organic impurities in the FBC spent bed were found. Its particle size distribution, as shown in Table 6 of the Technical Report, indicates a low fineness modules value of 1.8.

In an attempt to enhance the size gradation of the fine component of the matrix, a silicious natural fine aggregate, obtained from a quarry in southern Illinois, was used. The particle size, as shown in Table 6 of the Technical Report, was mostly within the aggregate grading recommended by ASTM C33. The fineness modules indicated a value of 2.8. The oven-dry and saturated surface dry specific gravity, and absorption are shown in Table 7 of the Technical Report. Tests on organic impurities failed to indicate the presence of any organic matters in the natural fine aggregate.

The limestone coarse aggregate was obtained from a quarry in southern Illinois. Its particle distribution was within the grading requirements of size number 56 recommended by ASTM C33 (maximum particle size of an inch). The remaining physical properties of the coarse aggregate are described in Table 8 of the Technical Report.

Tap water conforming with the requirements of ACI 301 was used during the blending of the concrete mixtures.

Table 9: Matrix Proportion Details for FBC/PCC Roller-Compacted Concrete Mixtures

Mix No.	FBC Spent Bed (%) *	Silicious Fine Aggregate (%)	PCC Fly Ash (%)	Portland Cement (%)	Limestone Coarse Aggregate (%)	Nominal Moisture Content (%)	Actual Moisture Content (%)
SURFACE COURSE SLABS							
B1S	21.6	14.4	9.0	----	55.0	6.2	5.975
B3S	18.0	12.0	15.0	----	55.0	6.97	6.48
B5S	13.5	9.0	22.5	----	55.0	7.0	6.56
B1PS	19.1	14.4	6.5	5.0	55.0	6.71	6.62
B3PS	15.5	12.0	12.5	5.0	55.0	6.69	6.29
B5PS	11.0	9.0	20.0	5.0	55.0	6.84	6.47
C3S	26.67	----	13.33	----	60.0	7.67	6.4
C5S	20.0	----	20.0	----	60.0	7.74	6.58
C3PS	24.17	----	10.83	5.0	60.0	7.95	6.78
C5PS	17.5	----	17.5	5.0	60.0	7.62	6.37
C1PS	29.5	----	5.5	5.0	60.0	8.27	7.15
BASE COURSE SLABS							
B1B	21.6	14.4	9.0	----	55.0	6.2	5.975
B3B	18.0	12.0	15.0	----	55.0	6.97	6.48
B5B	13.5	9.0	22.5	----	55.0	7.0	6.56
C1B	32.0	----	8.0	----	60.0	8.0	7.08
C3B	26.67	----	13.33	----	60.0	7.67	6.4
C5B	20.0	----	20.0	----	60.0	7.74	6.58

* Note: All percentages are by weight of total dry solid

DISCLAIMER STATEMENTS

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Table 10: Matrix Proportion Details for FBC/PCC Vibratory Placed Concrete Mixtures

SURFACE COURSE SLABS									
Mix No.	Slump (in.)	FBC Spent Bed (lb/yd ³)	PFC Fly Ash (lb/yd ³)	Portland Cement (lb/yd ³)	Natural Coarse Aggregate (lb/yd ³)	Natural Fine Aggregate (lb/yd ³)	Mixing Water (lb/yd ³)	W/C Ratio +	Yielded Volume (yd ³)
AS	4½ ±¼	780.58	237.37	313.53	1433	629.69	425.24	0.55	1.059
BS	5¼ ±¼	1040.77	237.37	313.53	1433	314.85	484.70	0.60	1.094
CS*	5¼ ±¼	0.0	0.0	500.	1433	1680.	310.	0.62	0.995
* Reference Mixture + Weight Ratio									
BASE COURSE SLABS									
AB	3 ±¼	1300.97	237.37	313.53	1433	0.0	549.11	0.66	1.134
BB	4½ ±¼	780.58	237.37	313.53	1433	629.69	425.24	0.55	1.059
CB	4½ ±¼	780.58	356.05	156.76	1433	629.69	405.42	0.55	1.043