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TECHNICAL REPORT
March 1 through May 31, 1995

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

DOE Cooperative Agreement Number: DE-FC22-92PC92521 (Year 3)
ICCI Project Number: 94-1/3.1A-4M
Principal Investigator: Nader Ghafoori, Department of Civil Engineering
and Mechanics, Southern Illinois University at
Carbondale
Project Manager: Daniel Banerjee, Illinois Clean Coal Institute

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 under 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 applications.

During this reporting period, the long-term durability of the field and laboratory vibratory-placed FBC/PCC surface course concrete mixtures, and strength properties of the field and laboratory FBC/PCC roller compacted surface and base concrete slabs were evaluated. The evaluation of shrinkage/expansion, flexural strength, stiffness, and long-term durability of the FBC/PCC roller compacted concrete slabs, and freeze-thaw performance of the field vibratory-placed FBC/PCC base course concrete mixtures are on-going and will be dealt with in the next quarterly report.

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EXECUTIVE SUMMARY

Preparation of Laboratory and Field Specimens

The matrix constituents and proportions of the field vibratory-placed and roller compacted FBC/PCC concrete mixtures were discussed in the first quarterly report. The fabrication of the vibratory-placed laboratory samples has also been detailed in the last quarterly report. The equivalent laboratory-made specimens of RCC slabs were prepared at their optimum moisture content using Proctor Compaction method. Upon fabrication, the laboratory specimens were wrapped with a plastic membrane to prevent moisture loss until the testing day. They were tested immediately after removal from plastic curing membrane (sealed at testing). The saturated samples were placed in water for two days prior to testing. In contrast, the field slabs were covered with polyethylene sheeting for a period of two to three weeks. Field-cored samples were tested under (1) "air-dry" condition (air-dry testing) and (2) "saturated" condition (soaked at testing) by placing them in water for a period of 48 hours prior to testing.

For the laboratory samples, cylindrical specimens of 4 x 4.5 inches were used for determination of compression, split-tension and modules of elasticity. For the field investigation of the RCC surface and base mixtures cylindrical specimens of 4 x 8 inches and 3 x 6 inches, respectively, were used to attain the strength properties.

Long-term Durability of Field Vibratory-Placed FBC/PCC Surface Course Concrete Mixtures

The rapid freezing and thawing performance, expressed in terms of mass loss, of the vibratory-placed surface course FBC/PCC concrete mixtures is shown in Table 1. The mixture "BS" exhibited the least resistance and failed within 10 F-T cycles. The inspection of the field slab revealed a similar condition, as documented through its surface scaling, under freezing and thawing regime of the winter climate. The slab of the mixture "AS" displayed a more resistance than that of group "BS" and failed at about 30 F-T cycles. Field inspection has shown no sign of deterioration after a winter of freezing and thawing cycles. Also as shown in Table 1, the freezing and thawing performance of the control concrete slabs (CS) which was far superior than that of the FBC/PCC mixtures. This can be attributed to the frost-resistant natural fine aggregate and the rich paste used in the fabrication of the control concrete mixture.

Figures 1 through 4 illustrate the abrasion resistance of vibratory-placed field and the equivalent laboratory-made samples under dry and wet surface conditions. In general, depth of wear increased with abrasion time and reduced drastically when testing conditions changed from dry to wet surface. The slab of the mixture "AS" displayed more resistance to wear under both dry and wet surface conditions.

Strength Properties of Laboratory and Field RCC Surface and Base Course Mixtures

The influence of mix proportion, curing age, and testing conditions on compression and split-tension behavior of roller compacted FBC/PCC surface and base course slabs were

investigated, and the results are presented in Figures 5 through 10. The test results indicate that the FBC/PCC mixes continued to gain strength with curing age. This trend follows the general pattern of conventional concrete. Both compressive and split-tensile strengths greatly depended on the mix proportion and the fly ash content of the matrix. The strength properties improved as the FBC spent bed to PCC fly ash ratio decreased.

While the addition of Portland cement (5% by weight of total dry solid) did not improve the compressive strength, it enhanced the tensile-splitting of RCC slabs. The average ratios of split-tension to compression strength were typical of those expected for conventional concrete and the ratio decreased as the age of concrete (or strength) increased. The influence of moisture (wet or dry) at various curing ages reduced as the fly ash content of the matrix increased.

Table 2 presents the strength properties of the equivalent laboratory-made RCC specimens. Excellent agreement was found between the field and laboratory samples. Bi-weekly inspections of the paved surfaces have been conducted for possible deterioration and surface cracks. After 9 months from the date in which the slabs were cast, mixture no. "BS" has experienced surface scaling due to freezing and thawing cycles of the winter climate. The other slab sections are crack-free and remain in excellent surface conditions.

**Figure 1: Field Abrasion Resistance FBC/PCC
Vibratory Placed Concrete Mixtures (Dry at Testing)**

**Figure 3: Laboratory Abrasion Resistance FBC/PCC
Vibratory Placed Concrete Mixtures (Dry at Testing)**

**Figure 2: Field Abrasion Resistance of FBC/PCC
Vibratory Placed Concrete Mixtures (Wet at Testing)**

**Figure 4: Laboratory Abrasion Resistance of FBC/PCC
Vibratory Placed Concrete Mixtures (Wet at Testing)**

Figure 5-a: Field Air-dry Compressive Strength of Surface Course FBC/PCC Roller Compact Concrete Mixtures

Figure 6-a: Field Soaked Compressive Strength of Surface Course FBC/PCC Roller Compact Concrete Mixtures

Figure 5-b: Field Air-dry Compressive Strength of Surface Course FBC/PCC Roller Compact Concrete Mixtures

Figure 6-b: Field Soaked Compressive Strength of Surface Course FBC/PCC Roller Compact Concrete Mixtures

Figure 7-a: Field Air-dry Split-tension Strength of Surface Course FBC/PCC Roller Compact Concrete Mixtures

Figure 7-b: Field Air-dry Split-tension Strength of Surface Course FBC/PCC Roller Compact Concrete Mixtures

Figure 8-a: Field Air-dry Compressive Strength of Base Course FBC/PCC Roller Compact Concrete Mixtures

Figure 8-b: Field Air-dry Compressive Strength of Base Course FBC/PCC Roller Compact Concrete Mixtures

Figure 9-a: Field Soaked Compressive Strength of Base Course FBC/PCC Roller Compact Concrete Mixtures

Figure 9-b: Field Soaked Compressive Strength of Base Course FBC/PCC Roller Compact Concrete Mixtures

Figure 10-a: Field Air-dry Split-tension Strength of Base Course FBC/PCC Roller Compact Concrete Mixtures

Figure 10-b: Field Air-dry Split-tension Strength of Base Course FBC/PCC Roller Compact Concrete Mixtures

Table 1: Freezing and Thawing Laboratory Testings of Field Vibratory Placed FBC/PCC Concrete Mixtures

Mixture No.	Number of Freezing and Thawing Cycles											
	5	10	15	20	25	30	35	40	45	50	55	60
	Mass Loss (%)											
AS	0.0	0.0	0.45	0.45	1.35	2.69	5.16	7.17	10.99	16.14	21.52	32.51
BS	7.82	58.77	-	-	-	-	-	-	-	-	-	-
CS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.46	0.46

Mixture No.	Number of Freezing and Thawing Cycles											
	65	70	75	80	85	90	95	100	105	110	115	120
	Mass Loss (%)											
AS	40.13			-	-	-	-	-	-	-	-	-
BS	-	-	-	-	-	-	-	-	-	-	-	-
CS	0.46	0.46	0.69	0.69	0.69	0.92	0.92	0.92	0.92	0.92	IP	IP

- Slight flaking
+ Slight chipping

* Noticeable cracking in specimens
Severe flaking and chipping

IP = In Progress

Table 2: Strength Properties of Laboratory Roller Compacted FBC/PCC Concrete Mixtures

Mixture No.	Nom. Moisture (%)	Wet Density (pcf)	Sealed Compression Strength * (psi)					Soaked Compressive Strength * (psi)					Sealed Split-Tensile Strength * (psi)			
			Curing Age (days)					Curing Age (days)					Curing Age (days)			
			7	28	60	90	180	7	28	60	90	180	28	60	90	180
B1S/B1B	6.67	142.90	-	3018	-	4910	-	-	2200	-	3750	-	311	461	537	576
B3S/B3B	6.47	143.62	-	3201	-	5808	-	-	2924	-	4516	-	385	507	571	611
B5S/B5B	6.34	144.12	-	4010	-	6513	-	-	3418	-	5688	-	409	516	595	648
C1B	8.60	142.90	716	2121	2836	3925	4387	426	1507	2275	3003	3215	317	416	491	520
C3S/C3B	8.40	143.50	1024	3152	4186	5415	5637	907	2729	3797	4823	4949	390	472	507	568
C5S/C5B	8.13	144.00	1630	3841	5503	6215	6307	1352	3334	4653	5358	5482	423	511	549	604

* Obtained from 4 x 4.5 inches laboratory-made cylinders

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 6 x 12 ft in size. After construction, two major tasks, field monitoring and laboratory testings 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 long-term durability of the field and laboratory vibratory-placed FBC/PCC surface course concrete mixtures, and strength properties of the field and laboratory FBC/PCC roller compacted surface and base concrete slabs were evaluated. The evaluation of shrinkage/expansion, flexural strength, stiffness, and long-term durability of the FBC/PCC roller compacted concrete slabs, and freeze-thaw performance of the field vibratory-placed FBC/PCC base course concrete mixtures are on-going and will be dealt with in the next quarterly report.

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 in landfills, causing adverse environmental and economical problems.

EXPERIMENTAL PROCEDURE

The strength and long-term characteristics of the field and laboratory specimens were evaluated based on ASTM C666, procedure A, (rapid freezing and thawing of concrete mixtures), ASTM C779, Ball Bearings (Abrasion resistance of concrete mixtures), ASTM C39 (unit weight and compressive strength), and ASTM C496 (split-tensile strength).

PREPARATION OF LABORATORY AND FIELD SPECIMENS

The matrix constituents and proportions of the field vibratory-placed and roller compacted FBC/PCC concrete mixtures were discussed in the first quarterly report. The fabrication of the vibratory-placed laboratory samples has also been detailed in the last quarterly report. The equivalent laboratory-made specimens of RCC slabs were prepared at their optimum moisture content using Proctor Compaction method. Upon fabrication, the laboratory specimens were wrapped with a plastic membrane to prevent moisture loss until the testing day. They were tested immediately after removal from plastic curing membrane (sealed at testing). The saturated samples were placed in water for two days prior to testing. In contrast, the field slabs were covered with polyethylene sheeting for a period of two to three weeks. Field-cored samples were tested under (1) "air-dry" condition (air-dry testing) and (2) "saturated" condition (soaked at testing) by placing them in water for a period of 48 hours prior to testing.

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RESULTS AND DISCUSSION

The rapid freezing and thawing performance, expressed in terms of mass loss, of the vibratory-placed surface course FBC/PCC concrete mixtures is shown in Table 1 of the technical report. The mixture "BS" exhibited the least resistance and failed within 10 F-T cycles. The inspection of the field slab revealed a similar condition, as documented through its surface scaling, under freezing and thawing regime of the winter climate. The slab of the mixture "AS" displayed a more resistance than that of group "BS" and failed at about 30 F-T cycles. Field inspection has shown no sign of deterioration after a winter of freezing and thawing regimen. Also as shown in Table 1, the freezing and thawing performance of the control concrete slabs (CS) which was far superior than that of the FBC/PCC mixtures. This can be attributed to the frost-resistant natural fine aggregate and the rich paste used in the fabrication of the control concrete mixture.

Figures 1 through 4 of the technical report illustrate the abrasion resistance of vibratory-placed field and the equivalent laboratory-made samples under dry and wet surface conditions.

In general, depth of wear increased with abrasion time and reduced drastically when testing conditions changed from dry to wet surface. The slab of the mixture "AS" displayed more resistance to wear under both dry and wet surface conditions.

The influence of mix proportion, curing age and testing conditions on compression and split-tension behavior of roller compacted FBC/PCC surface and base course slabs were investigated, and the results are presented in Figures 5 through 10 of the technical report. The test results indicate that the FBC/PCC mixes continued to gain strength with curing age. This trend follows the general pattern of conventional concrete. Both compressive and split-tensile strengths greatly depended on the mix proportion and the fly ash content of the matrix. The strength properties improved as the FBC spent bed to PCC fly ash ratio decreased.

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Table 2 of the technical report presents the strength properties of the equivalent laboratory-made RCC specimens. Excellent agreement were found between the field and laboratory samples. Bi-weekly inspections of the paved surfaces have been conducted for possible deterioration and surface cracks. After 9 months from the date in which the slabs were cast, mixture no. "BS" has experienced surface scaling due to freezing and thawing cycles of the winter climate. The other slab sections are crack-free and remain in excellent surface conditions.

DISCLAIMER STATEMENTS

DOE and Illinois Cooperative Projects- "This report was prepared by Dr. Nader Ghafoori of Southern Illinois University at Carbondale with support, in part by grants made possible by the U.S. Department of Energy Cooperative Agreement Number DE-FC22-92521 and the Illinois Department of Energy through the Illinois Coal Development Board and the Illinois Clean Coal Institute. Neither Dr. Nader Ghafoori of Southern Illinois University at Carbondale nor any of its subcontractors nor the U.S. Department of Energy, Illinois Department of Energy & Natural Resources, Illinois Coal Development Board, Illinois Clean Coal Institute, nor any person acting on behalf of either:

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PROJECT MANAGEMENT REPORT

March 1 through May 31, 1995

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Principal Investigator: Nader Ghafoori, Department of Civil Engineering
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Project Manager: Dr. Dan Banerjee, Illinois Clean Coal Institute

COMMENTS

None.

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PROJECTED AND ESTIMATED EXPENDITURES BY QUARTER

Quarter*	Types of Cost	Direct Labor	Fringe Benefits	Materials and Supplies	Travel	Major Equipment	Other Direct Costs	Indirect Cost	Total
Sept. 1, 1994 to Nov. 30, 1994	Projected	4,929	0	1,250	600	5,000	6,250	1,803	19,832
	Estimated	627	0	1,633	218	4,991	8,243	1,571	17,283
Sept. 1, 1994 to Feb. 28, 1995	Projected	7,858	0	2,500	1,400	5,000	18,500	3,126	34,384
	Estimated	1,546	0	2,585	1,135	4,991	18,680	3,188	32,125
Sept. 1, 1994 to May 31, 1995	Projected	10,787	0	3,750	1,950	5,000	28,750	4,424	48,661
	Estimated	3,206	0	3,867	1,875	4,991	22,234	3,912	40,085
Sept. 1, 1994 to Aug. 31, 1995	Projected	18,876	2,071	5,000	2,650	5,000	36,616	7,021	77,234
	Estimated								

*Cumulative by Quarter

CUMULTIVE COSTS BY QUARTER

A Field Demonstration Project Utilizing FBC/PCC Residues for Paving Materials

● = Projected Expenditures -----
▲ = Actual Expenditures _____

Total Illinois Clean Coal Institute Award \$77,234

SCHEDULE OF PROJECT MILESTONES

Begin
Sept. 1
1994

Hypothetical Milestones:

- A: Research assistant employed (Task 1)
- B: Preparation of raw material (Task 2)
- C: Physico-chemical properties of raw materials (Task 3)
- D: Preconditions studies of FBC spent bed residues (Task 4)
- E: Construction of field slab pavements (Task 5)
- F: Evaluation of field cored specimens for strength, expansion, shrinkage, and long-term durability (Task 6)
- G: Evaluation of laboratory specimens of equivalent field mixes for bleeding, time of setting, air content, strength, expansion, shrinkage, and long-term durability (Task 7)
- H: Technical and Project Management Reports