Demonstration of CFB Ash as a Cement Substitute in Concrete Pier Foundations for a Photo-Voltaic Power System at SIUC

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ABSTRACT

A large volume application for two fly ashes in cement concrete applications has been demonstrated at Southern Illinois University. Using 23% F-fly ash and CFB fly ash in conventional concrete, 48 foundation piers for supporting a photo-voltaic array were constructed. The fly ash-cement concrete mix implemented has demonstrated strength properties that are comparable to that of conventional concrete. Synergy between F-fly ash and CFB fly ash is indicated for the achieved results that compare favorably to conventional concrete. Very low swelling has been measured for samples made from the implemented mix. The installation is performing up to expectations for the past 2.5 years. This successful demonstration holds a significant promise for other similar applications.

INTRODUCTION AND BACKGROUND

In March 2004, Southern Illinois University at Carbondale's (SIUC) physical plant services office (PSO) planned an installation of a 28.2 KW photo-voltaic (PV) array as part of an Illinois Department of Commerce and Economic Opportunity (DCEO) grant. This photovoltaic system would contain 176 PV modules, mounted on 22 racks of 8 modules each. The racks would be arranged in 2 rows of 11 each. Each rack would have four feet and adjacent racks feet would share a cylindrical concrete foundation pier so that there would be a total of 48 piers in 4 rows of 12 each. The array would be installed on a hillside with an approximate 10 degree incline to the north. Due to the slope, the front (southern) row of piers on each sub-array would be taller above-grade than the back row. The back row above-grade height would be approximately 0.3048 m to avoid damage from mower blades. This set the front row piers at an above-grade height of approximately 0.762 m. Estimating a worst-case frost depth of 0.6 m, each pier would be installed to 0.91 m below grade. This made the front row piers 1.68 m tall and the back row piers 1.22 m tall. Each pier would be formed using "sonotubes" to have a 0.3048 m diameter for upper surface area requirements. Thus the total volume of concrete required would be approximately 0.12 m^3 per front pier and 0.09 m^3 per back pier. The total volume of concrete for 48 piers would be 5.1 m^3. Each pier would be reinforced with an internal steel rebar cage. It was desired that the PV arrays be implemented on coal combustion byproduct (CCB) based foundation piers. To design an appropriate mix with suitable properties for these piers, the authors conducted laboratory studies which were immediately followed by the demonstration. The results of these studies and demonstration are presented in this paper. Figure 1 shows the final array installation on CFB fly-ash substituted cement concrete foundation piers.

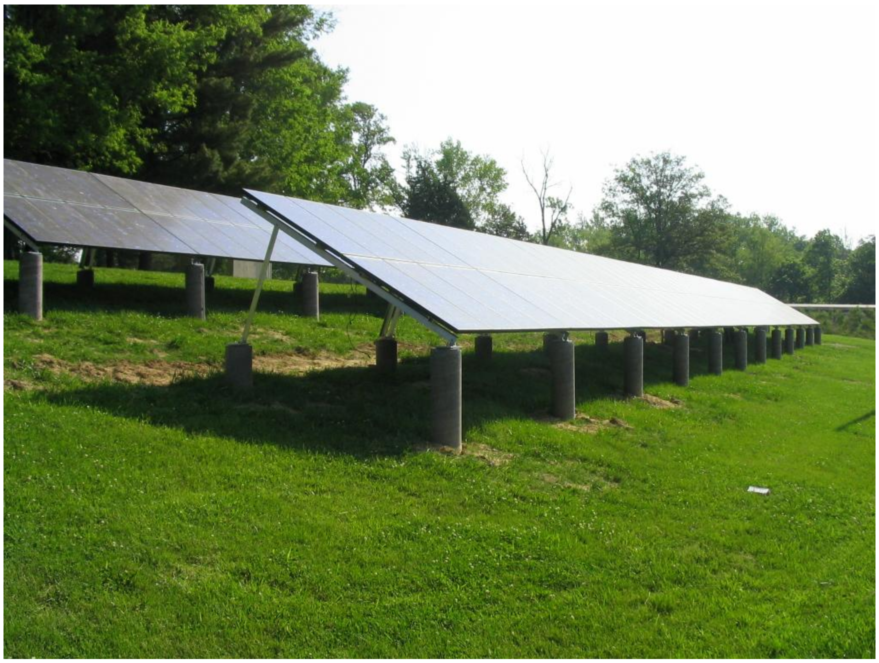

Figure 1. Photo-voltaic array deployment on CCBs based concrete foundation piers.

EXPERIMENTAL PROCEDURES

Laboratory Experiments

Mix Preparation

During the mix design phase of this study, the concrete mix was prepared in an electrically driven counter-current pan mixer of 0.02 m^3 capacity (Figure 2a). Coarse aggregate was added to the mixer along with about 30% of the total required water. This was followed by addition of fine aggregate, circulating fluidized bed (CFB) fly ash, 30% of the required water, F-fly ash, and another 30% of the required water and cement in that order. This was followed by addition of an aeration chemical diluted with 10% of the total required water. The aeration agent as well as all the water was added slowly to ensure uniform distribution of these in the mix. After about 300 s of mixing time, a sample of the mix was extracted and tested for slump. If the slump was less than 10-13 cm, additional water was added till this desired slump was achieved. Subsequently, measurements of entrained air were made in an aeration meter. The CFB ash used in these experiments was pre-hydrated using 25% water by weight. From each batch of mix, nine 10.16 x 20.32 cm cylindrical samples were prepared in plastic molds, coated with 10W30 motor oil to facilitate demolding, using three lifts and using the standard rodding procedure. The prepared samples were leveled at the top and covered with lids to prevent drying at the surface (Figure 2b). After 24 h, the samples were demolded and put under water for curing. The water temperature was maintained constant at 21^{o}C.

(a) (b)

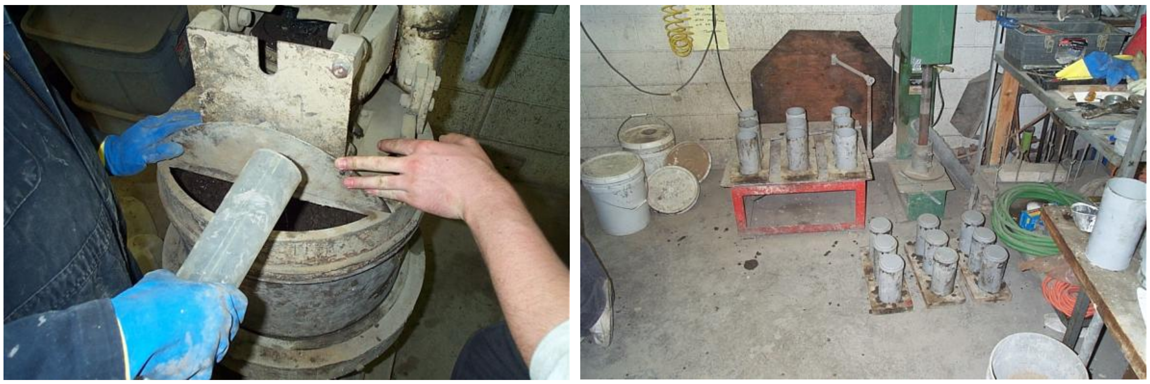

Figure 2. (a) Counter-current pan mixer used for laboratory sample preparation, and, (b) 10.16 cm x 20.32 cm laboratory samples in molds.

A total of three candidate mixes were designed along with a control conventional concrete mix for comparison purposes. Eighteen samples of each mix including the control mix were prepared in 8 batches of mixes. The dimensions of a few samples from each batch were accurately measured using a vernier caliper immediately following their demolding after 24 h. After the appropriate curing time had passed, samples were tested for compressive and split tensile strengths with 3 and 2 repetitions, respectively. After each test curing period, the dimensions of the measured samples were recorded to calculate the volumetric swelling. The strength testing was conducted on an M&L testing machine with a maximum capacity of 450,000 lbs.

Field Demonstration

Prior to the full scale field implementation, one trial pier was poured at the site using a laboratory concrete mixer. During the implementation phase of the piers, measured amounts of pre-hydrated CFB ash and F-ash was delivered to a ready mix plant. The ashes were loaded in a concrete truck and other ingredients were added on top along with the aeration agent. Sufficient water was added to the mix to achieve a slump value of approximately 5 cm. The super-plasticizer and additional water was added on site to achieve a slump of 10-13 cm just before pouring the mix in the sonotube forms. During implementation, the slump of the mix had a tendency to reduce with time. This was possibly a result of further hydration of CFB ash as well as the reduced effectiveness of the super-plasticizer with time. Hence, small amount of additional water was added as and when required to maintain a slump between 10 and 13 cm. This implementation was conducted in four phases with 12 foundation piers in each phase.

Field QA/QC Procedures

As a field QA/QC procedure, 18-20, 15.24 cm by 30.48 cm cylindrical samples were prepared during each of the four phases of implementation. These samples were demolded after 24 h and cured under water prior to compressive and indirect tensile testing after 7, 14 and 28 d of curing time.

RESULTS AND DISCUSSION

Mix Design

The traditional approach to using F-fly ash or C-fly ash as a cement substitute involves up to 15- 25% replacement of cement with fly ash. However, this only represents 3-5% fly ash in the concrete mix. To increase the utilization of coal combustion products in concrete applications, the approach utilized here involved replacement of up to 64% fine aggregate in the concrete with CFB ash and F-ash from a cyclone boiler burning bituminous Illinois coal. This represents a total of 23% fly ash in concrete. The CFB ash used in this study was obtained from the SIU power plant, where this project was implemented. The F-ash was obtained from Southern Illinois Power Cooperative's (SIPC) Lake of Egypt power plant. Three candidate mixes were designed by the authors based on past experience. These mix compositions are shown in Table 1. Samples were prepared in the laboratory for the three (3) candidate mixes and an equivalent concrete mix (control mix). The details of sample preparation are provided in Table 2.

The prepared samples were tested for 7 and 14 d strengths and were also monitored for swelling, which can be a concern while using CFB ash in such applications. At the end of 7 d of curing, Mix 1 and Mix 2 exhibited higher compressive strength (11.1 MPa and 8.2 MPa) than conventional concrete control mix (6.8 MPa). Mix 1 was characterized by 12% CFB ash in the mix while Mix 2 had 13% CFB ash and 10% F-ash in the mix. Interestingly, at the end of 14 d of curing, the control mix gained strength faster than Mix 1 reaching about the same strength at 11.7 MPa. Mix 2 however registered an even larger strength gain reaching 13.1 MPa at the end of 14 d. This behavior is explained by the presence of F-ash in Mix 2 which is known to add long term strength.

Based on the 14 d results available at that time, Mix 2 was selected for implementation. The 28 d strength data on the laboratory samples validated the selection of Mix 2 for implementation. After 28 d of curing, Mix 1 and the control mix gained strength at the same rate reaching a compressive strength of 17.2 MPa. Mix 2, which was the selected mix, registered a drastic gain in compressive strength reaching 35.5 MPa. In order to compare the strengths of the control mix with the other mixes, it must be noted that the control mix achieved a very high level of air entrainment (15%), whereas, the other mixes had only 1.5% air. An acceptably low 28 d swelling of 3.3% was measured for the selected mix. The summary laboratory mix design results are presented in Table 3.

Table 1. Test mixes for SIU's PV-array foundation piers.

Mix	Cement (%)	Fine Aggregate (%)			Coarse Aggregate (%)	Total (%)	Fine Aggregate Replacement (%)
		Sand	F-Ash	CFB Ash			
Control	16	36	-	-	48	100	-
Mix 1	16	24	-	12	48	100	33
Mix 2	16	13	10	13	48	100	64
Mix 3	16	14	-	22	48	100	64

Table 2. Laboratory sample preparation for mix selection.

Mix	Volume (m^3)	Plasti-cizer (g)	Slump (cm)	Water/ Cement Ratio	Entrain-ment Agent (g)	Air Entrain-ment (%)
Control - Batch 1	0.02	-	13	0.44	7.56	15
Control - Batch 2	0.02	-	13	0.43	7.56	14
Mix 1- Batch 1	0.02	-	10	0.64	7.56	1.7
Mix 1- Batch 2	0.02	-	13	0.64	7.56	1.0
Mix 2 - Batch 1	0.02	-	11.5	0.73	9.46	1.6
Mix 2 - Batch 2	0.02	-	11.5	0.73	9.46	1.25
Mix 3 - Batch 1	0.02	-	11.5	0.66	9.46	1.2
Mix 3 - Batch 2	0.02	-	13	0.68	9.46	1.3

Table 3. Summary results from laboratory testing of deigned mixes. (Reported compression data is an average of 3 samples and split tension data is an average of 2 samples.)

Sample	7 d			14 d			28 d		
	Comp-ressive Str-ength (Mpa)	Elastic Mod-ulus (MPa)	Split Tensile Str-ength (Mpa)	Comp-ressive Str-ength (MPa)	Elastic Mod-ulus (MPa)	Split Tensile Str-ength (MPa)	Comp-ressive Str-ength (MPa)	Split Tensile Str-ength (MPa)	Swe-lling (%)
Control	7.6	1276	1.2	11.2	2475	1.5	16.8	1.6	0.50
Mix 1	11.1	1758	1.1	12.2	2034	1.7	17.3	1.7	3.16
Mix 2	8.2	1103	1.1	13.0	1669	1.8	35.5	2.8	3.30
Mix 3	7.6	752	0.9	10.9	1365	1.0	9.3	0.9	2.15

Field Demonstration

After appropriate field-prep work was conducted by SIU physical plant, 1.9-3.5 m^3 of the selected mix was prepared and poured in each of the four phases of implementation. Activities involved in the implementation of these piers are presented in Figures 3 and 4 with the deployed PV array on the CCBs based concrete foundation piers shown earlier in Figure 1.

As a field QA/QC procedure, 18-20 15.24 cm by 30.48 cm cylindrical samples were also prepared during each of the four phases of implementation. The compiled test data for the field QA/QC samples is presented in Table 4. It can be seen that the 7 d and 14 d strength results for the field implementation samples indicate that these samples far exceeded both the design and control mix laboratory compressive strengths both after 7 and 14 d of curing. The tensile strength of the field implementation samples was also higher than that for the laboratory design and control mix after 7 and 14 d of curing. The inter-group variability for the four groups of piers was also fairly low. The average 7 d compressive and tensile strengths for the field implementation samples were 12.4 MPa and 1.2 MPa. This compares with 6.8 and 1.2 and 8.2 and 1.1 MPa for the compressive and tensile strengths for the control and design mixes, respectively. The average 14 d compressive and tensile strengths for the field implementation samples were 19.7 MPa and 1.9 MPa. This compares with 11.2 and 1.5 and 13.0 and 1.8 MPa for the compressive and tensile strengths for the control and design mixes, respectively.

Table 4. Field implementation sample results.

Sample Set	Strength 7 d		Strength 14 d		Strength 28 d	
	Comp-ression (MPa)	Split Tension (MPa)	Comp-ression (MPa)	Split Tension (MPa)	Comp-ression (MPa)	Split Tension (MPa)
Control	6.8	1.2	11.2	1.5	16.8	1.6
Design	8.2	1.1	13.0	1.8	35.5	2.8
Phase 1	10.5	0.9	-	-	21.3	2.0
Phase 2	13.1	1.0	16.6	2.0	19.4	2.5
Phase 3	-	-	20.8	1.5	16.1	1.5
Phase 4	13.5	1.8	21.8	2.1	17.1	2.9

The compressive strength results after 28 d of curing present a few anomalies. On an average the 28 d strength of the QA/QC samples exceeded the compressive strength of the laboratory control mix but not of the laboratory designed mix. Note that the QA/QC samples had achieved strength which was significantly higher than the control or the designed mix after 7 and 14 d of curing. The most significant anomaly that appeared is the decline in strength after 28 d of strength compared to the strength after 14 d of curing time. This was observed in particular for the Phase 3 and Phase 4 samples. Swelling is offered as a possible explanation for this behavior. However it is unclear why this was an issue for only the Phase 3 and 4 samples. There is a possibility that the excess water used during these two phases to maintain better workability of the mix might have a role to play.

(a) (b) (c)

Figure 3. (a) CCBs based foundation pier being poured, (b) CCBs based foundation pier being poured with the steel rebar ready for insertion, and, (c) CCBs based foundation pier after 7 d curing time. Anchor bolt is visible on top.

(a) (b)

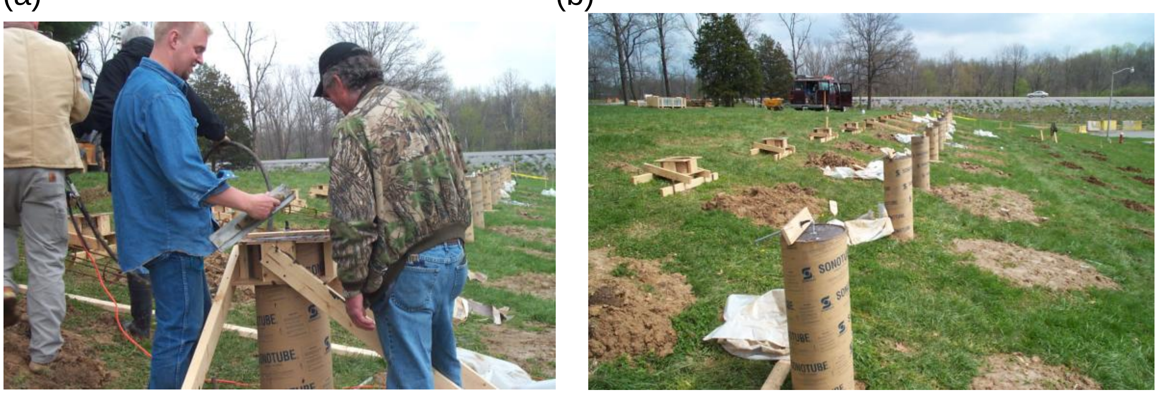

Figure 4. (a) CCBs based foundation pier being finished after being poured, and, (b) A row of twelve CCBs based foundation piers a few days after implementation. Forms for the second row of piers are ready and visible on the left. Preparations for the third and fourth rows are visible on the right.

CONCLUSIONS

All the available data indicates that the field implementation of the piers was very successful with the achieved strength values exceeding the design expectations. The piers are performing to expectations for the past three years and show no signs of deterioration of any kind.

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