FINAL TECHNICAL REPORT
May 15, 2001, through September 14, 2003

Project Title: LARGE VOLUME UTILIZATION OF ILLINOIS PCC DRY BOTTOM ASH IN CAST-IN-PLACE DRILLED SHAFTS AT MARION HOSPITAL

ICCI Project Number: 00US-2
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ABSTRACT

The primary purpose of this project was to demonstrate the performance of a concrete composite made with Illinois pulverized coal combustion (PCC) bottom ash when used in construction of drilled shafts. The goal of the proposed study was accomplished by conducting the Osterberg Cell (O-Cell) tests on two, full-size test drilled shafts at the Marion Hospital site and laboratory testing on concrete samples prepared during construction of the test drilled shafts. Based on the results obtained from a previous study, a concrete composite prepared by replacing 100 percent of natural fine aggregate with Illinois PCC bottom ash along with an equivalent conventional concrete were used to construct the drilled shafts to demonstrate the performance of a concrete composite. In addition, pullout tests on reinforcing bars of various sizes, embedded in several different concrete mixtures to various depths were conducted in the laboratory and field to compare the bond strength of concrete composites with the bond strength of equivalent conventional concretes. Four different concrete composites prepared using Illinois PCC bottom ash, and two control mixtures of conventional concrete, were used to perform the bond strength tests. The field tests on full-size drilled shafts and related laboratory testing showed that the concrete composite prepared using Illinois PCC dry bottom ash performed similar to that of an equivalent conventional concrete.

The strength data presented show that the compression strength of the concrete composite tested in this investigation was greater than the specified compression strength of 3,000 psi after 28 days of curing. The project structural engineer also approved the mix design for use in the drilled shafts. However, because of the liability issues, the concrete composite could not be used for the construction of production shafts. The general contractor as well as Southern Illinois University - Carbondale was unwilling to accept responsibility for any structural problems that may have arisen from the use of the new bottom ash concrete materials. As no party could be found to accept liability for the use of the new material, the goal of implementation of the bottom ash concrete in a commercial project could not be realized.

EXECUTIVE SUMMARY

The main objective of the proposed project was to demonstrate the performance of a concrete composite made with Illinois PCC dry bottom ash in drilled shafts. In addition, a study consisting of pullout tests on reinforcing steel bars of various sizes, embedded in several different concrete mixtures to various depths, were conducted in the laboratory and field to compare the bond strength of concrete composites with that of the equivalent conventional concretes. Summary of the results from both portions of the project is presented in this section. More detailed information about the testing procedures and results in presented in the subsequent sections.

Field Construction and Testing on Drilled Shafts

In order to demonstrate the performance of bottom ash concrete compared to that of an equivalent conventional concrete, Osterberg Cell (O-Cell) tests were conducted on two, full size shafts. One shaft was constructed using the concrete composite made with Illinois PCC dry bottom ash whereas the other shaft was constructed using an equivalent conventional concrete. Based on a previous study performed at Southern Illinois University – Carbondale (SIUC), concrete composites were prepared by replacing 100 percent of natural fine aggregate with Illinois PCC bottom ash. Table 1 shows the mixture designations with percent of different matrix constituents used to construct test drilled shafts.

Table 1: Mixture Constituents

Mixture Designation	Binders (%)		Fine Aggregates (%)		Remarks
	Portland Cement	PCC Fly Ash	PCC Dry Bottom Ash	Natural Sand	
CM	100	0	0	100	Control Mix
B100	100	0	100	0	

Both the shafts were 42-inches in diameter and approximately 40 foot deep. In the O-cell tests, the upward shaft movement provides information about frictional resistance between the concrete and the surrounding soil. Figure 1 shows response of load versus upward movement at the O-cell level for both the shafts tested using O-cell. This figure shows that the performance of the shafts constructed with the concrete composite is similar to that of the shaft constructed using conventional concrete.

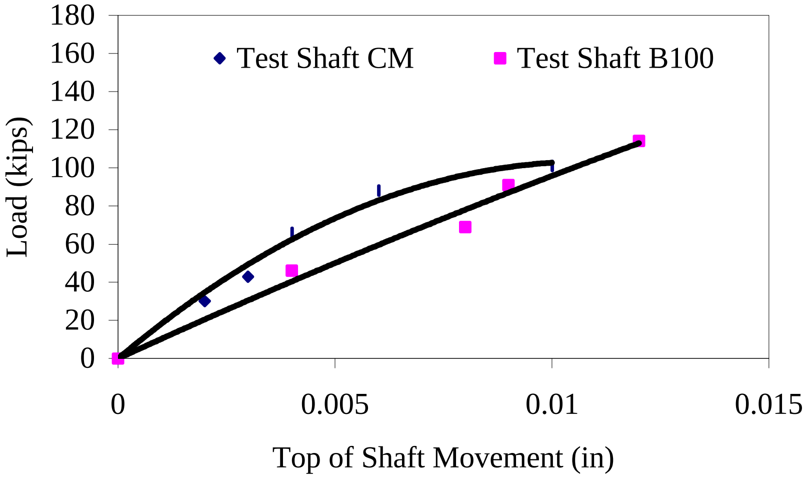


Figure 1. Load versus upward movement of shafts

Strength Tests on Samples made During Shaft Construction

Strength of concrete is commonly considered its most valuable property. The compressive strength test usually gives an overall picture of the quality of concrete because compressive strength is directly related to the structure of the hydrated cement paste. Moreover, the compressive strength of the concrete is almost invariably a vital element of structural design and is specified for compliance purposes.

The samples obtained during construction of test drilled shafts were tested at various curing ages to determine compression, split-tension, and flexural strengths of the concretes. Figure 2 shows the comparison of compressive strength of a concrete composite (B100) and conventional concrete (CM) at various curing ages. From Figure 2 it is clear that compressive strength of the composites increased with an increase in curing age. Results also show that the compressive strength of the concrete composite used in the investigation was less than that of conventional concrete up to a curing age of approximately 60 days. However, the compressive strength of the concrete composite was greater than the targeted compressive strength of 3,000 psi after 28 days of curing. After 90 days of curing, compressive strength of concrete composite made with Illinois PCC bottom ash was observed to be approximately equal to that of conventional concrete. The project structural engineer also approved the mix design for use in the drilled shafts. However, because of the liability issues, the concrete composite could not be used for the construction of production shafts. The general contractor as well as Southern Illinois University - Carbondale was unwilling to accept responsibility for any structural problems that may have arisen from the use of the new bottom ash concrete materials. As no party could be found to accept liability for the use of the new material, the goal of implementation of the bottom ash concrete in a commercial project could not be realized.

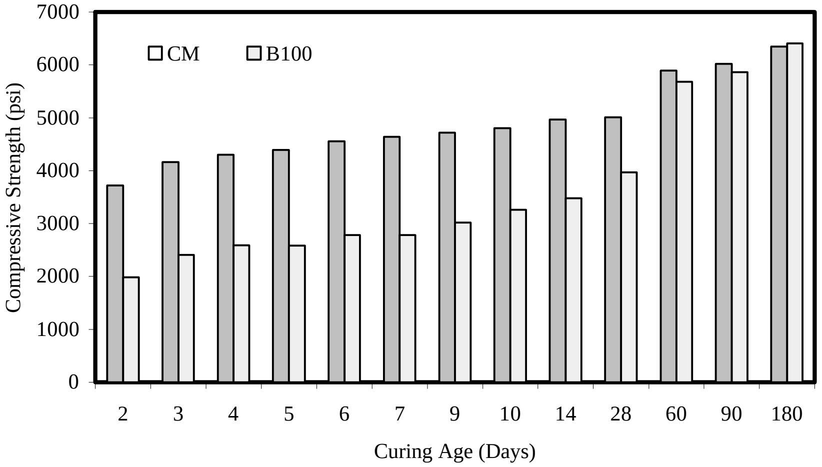


Figure 2. Comparison of compressive strength and influence of curing age on compressive strength of concrete composites

Bond Strength Test Results

Bond strength tests were performed on four concrete composites and two corresponding conventional concrete mixtures. The mixtures selected for the bond strength tests were based on the previous studies completed at SIUC. The mixtures designations starting with letter ‘D’ refer to the mixtures used for drilled shaft project and mixture designation starting with letter ‘P’ refer to the mixtures used for pre-cast concrete pile project.

Bond strength tests were performed in the laboratory on reinforcing bars embedded in cylindrical concrete samples and in the field on reinforcing bars embedded in trenches filled with concretes. From each batch of concrete, six cylinders, 6 inch diameter and 12 inch tall, were prepared with three different size reinforcement bars. Two cylinders with each bar size and corresponding embedment length were prepared for each concrete composite for a total of thirty-six cylindrical samples. The reinforcement bar sizes, No.’s 4, 6, and 8, with embedment lengths of 5, 8, and 10 inches, respectively, were used in the cylindrical samples. Using the same concrete batch, one large trench was prepared with three different size reinforcing bars and embedment lengths. The reinforcement bar sizes, No.'s 4, 6, and 8, with embedment lengths of 12, 15, and 18 inches, respectively, were used in the trenches.

Figure 3 shows the test results from cylindrical samples. In the figure, B100 refers to the concrete composite with 100 percent bottom ash, B50 refers to the concrete composite with 50 percent bottom ash, and CM refers to the control mixture. Letters D and P refer to the mixtures used for drilled shafts and precast concrete piles, respectively. It is clear from Figure 3 that in general, the bond strength of concrete composites made with Illinois PCC dry bottom ash is similar to that of conventional concrete. A similar observation was made from the results obtained from tests made on bars embedded in trenches filled with concretes.

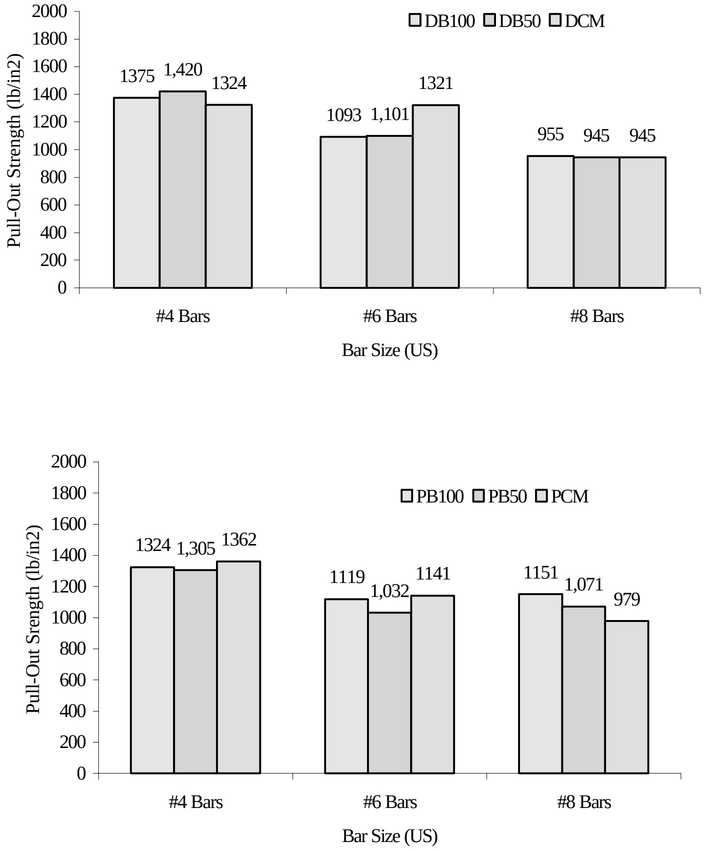


Figure 3. Bond strength test results from cylindrical samples

OBJECTIVE

Use of coal combustion by-products in construction of cast-in-place drilled shafts so far has been very limited, if any. The main objective of the proposed project was to demonstrate the performance of a concrete composite made with Illinois PCC bottom ash when used in the full-size drilled shafts. An additional study was conducted with an objective to compare bond strength of concrete composites containing Illinois PCC bottom ash with that of equivalent conventional concretes.

INTRODUCTION AND BACKGROUND

The Department of Civil Engineering at Southern Illinois University – Carbondale (SIUC) completed a research project titled “Field Utilization of Illinois PCC Fly Ash and Bottom Ash in Deep Foundations”, ICCI Project Number, 99-1/2.1B-6 in December 2000. The research project consisted of extensive laboratory and field-testing on concrete composites prepared using Illinois PCC bottom ash to identify viable mix proportions which have the potential of performing satisfactorily in cast-in-place drilled shaft foundations. Based on the laboratory testing, two mixture proportions were identified and tested in the field under field loading conditions on drilled shafts. Test results from this research investigation showed that the performance of concrete composites made by using Illinois PCC bottom ash was similar to that of conventional concrete.

In view of the prior laboratory and field investigations, the proposed project was intended to demonstrate the performance of a concrete composite containing Illinois PCC bottom ash by using it in a full-size test drilled shaft at the Marion Hospital site. In order to demonstrate the performance of bottom ash concrete compared to that of an equivalent conventional concrete, Osterberg cell (O-cell) tests were conducted on two, full size shafts. One shaft was constructed using the concrete composite containing Illinois PCC dry bottom ash whereas the other shaft was constructed using an equivalent conventional concrete. Based on a previous study performed at Southern Illinois University – Carbondale (SIUC), a concrete composite was prepared by replacing 100 percent of natural fine aggregate with Illinois PCC bottom ash. Both the shafts were 42-inches in diameter and approximately 40 foot deep.

EXPERIMENTAL PROCEDURES

Material Preparation (Task 1)

The materials used in this investigation were Type I Portland Cement as binder, crushed limestone as a coarse aggregate, natural sand and Illinois PCC dry bottom ash as a fine aggregate, and water.

ASTM Type I Portland cement, crushed limestone coarse aggregate, and natural fine aggregate were obtained from ODUM Concrete, Marion, Illinois. ODUM Concrete uses Portland cement from Lonestar Industries, Cape Girardeau, Missouri.

Illinois PCC dry bottom ash was obtained from City Water Light and Power (CWLP) in Springfield, Illinois. The CWLP uses coal from Elkhart, Illinois coal mine. Before transporting the bottom ash to the ready mix plant, it was sieved at the ash pond site using a U.S. standard #4 sieve.

Construction and Testing of Drilled Shafts (Task 1)

Construction of Test Drilled Shafts

Two test shafts were constructed at the Marion Hospital site. Both the shafts were 42-inches in diameter and approximately 40 foot deep. After completion of drilling for the shafts, the shafts were cleaned using an auger. A 2-foot thick bedding layer of concrete was placed in the shaft before lowering 9-inch diameter O-Cell into the shaft. Each O-Cell was mounted between 2 feet diameter and 1-inch thick steel plates. Figure 4 shows the picture of O-Cell attached to the steel frame and steel plates. Figure 5 shows the construction of drilled shafts in progress.

Figure 4. O-Cell attached to the steel frame and steel plates

Figure 5. Construction of shafts in progress

Preparation of Samples for Strength Testing

Concrete composite and conventional concrete used in this study was prepared at the ODUM Concrete in Marion, Illinois. The cylindrical and beam samples were prepared in the field from the concrete composite and conventional concrete to study the strength characteristics of the mixtures. The samples were prepared in accordance with ASTM C31 “Making and Curing Concrete Tests Specimens in the Field”. Figure 6 shows the picture of sample preparation in progress.

Figure 6. Sample preparation for strength testing in progress

Testing of Drilled Shafts

The load testing was carried out in general compliance with the pertinent ASTM Standards. O-cell tests started by pressurizing the O-cell in order to break the tack welds that hold the cell closed (for handling and construction of the shaft) and to form the fracture plane in the concrete surrounding the base of the O-cell. After the break occured, O-cell was immediately depressurized and then loading was started. O-cell load testing was performed by pressurizing the O-cell. The applied load was determined from the cell's pressure versus load calibration. The load was increased until the ultimate capacity of the side shear resistance above the O-cell was reached and/or the maximum stroke of the O-cell was approached. Each loading increment was held constant for eight minutes by manually adjusting the pressure of the loading device. Figure 7 shows the testing of shafts in progress.

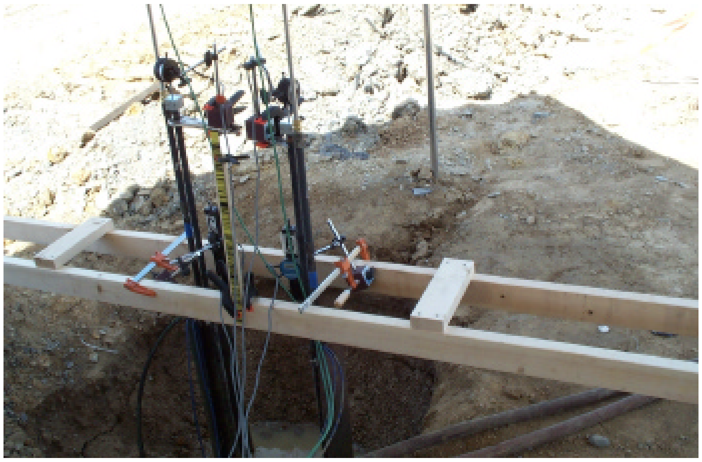


Figure 7. Testing of Drilled Shafts in Progress

In the O-cell tests, the upward shaft movement provides information about frictional resistance between the concrete and the surrounding soil. Figure 1 shows response of load versus upward movement at the O-cell level for both the shafts tested using O-cell. This figure shows that performance of the shafts constructed with concrete composites is similar to that of the piles constructed using conventional concrete.

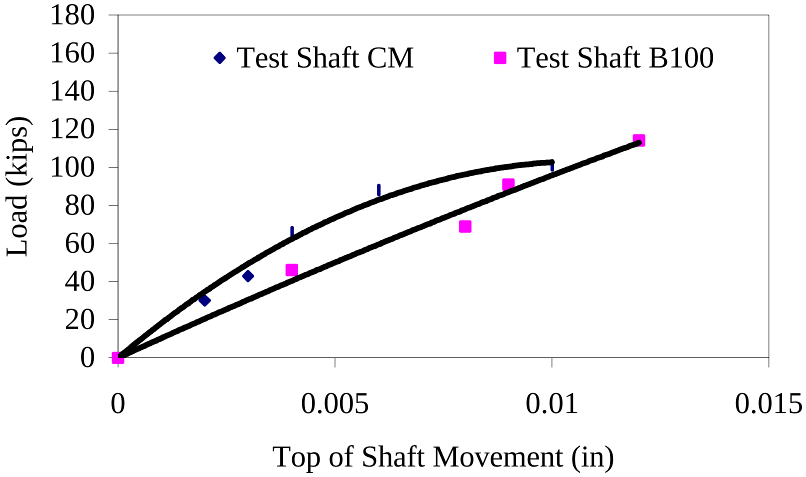


Figure 1. Load versus upward movement of shafts

Testing of Samples Prepared During Construction of Shafts

Compression, splitting-tensile, and flexural tests were performed to obtain the strength characteristics of concrete. The description of each testing method is given below.

<u>Compression Test</u>. The 4 x 8 in (101.6 x 203.2 mm) cylindrical specimens were capped with a thin layer of sulfur on both ends, as specified by ASTM C 617 “Standard Practice for Capping Cylindrical Concrete Specimens.” The reason for capping was to ensure that the ends of the specimen were plane and perpendicular to the axis of loading. To ensure the application of uniaxial compression loading, the surfaces of the upper and lower platens of the compression machine were cleaned and the specimen was placed on the hardened steel surface of the lower platen, aligning the specimen with the center of the upper spherically seated platens. Following the specification of ASTM C 39 “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens”, the load was applied continuously at a rate of 22,500 lb/min until failure.

<u>Splitting-Tensile Test</u>. The splitting-tensile test was performed in accordance with ASTM C 496 "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens." Prior to testing, each specimen was marked with a center line for accurate positioning under center loading. The 4 x 8 inch (101.6 x 203.2 mm) cylindrical specimen was placed with axis parallel to the loading platens. Two plywood bearing strips 1/8 inches (3.2mm) thick, 1 inch (25.4mm) wide, and 10 inch (254mm) long, were placed between the specimen and the upper and lower bearing surfaces. The load was applied uniformly, at a constant rate of 7500 lb/min, along the length of the specimen. The specimen splits into two halves when failure occurred. The failure load was recorded.

<u>Flexural Test</u>. The flexural test followed the specification of ASTM C 78 "Standard Test Method for Flexural Strength of Concrete (using Simple Beam with Third-Point Loading)." Prior to testing, each 4 x 4 x 14 in (101.6 x 101.6 x 355.6 mm) specimen was marked with four lines for accurate positioning under loading heads. The load was applied continuously at a rate of 13 lb/min until the failure occurred.

Preparation of Samples and Trenches for Bond Strength Tests (Task 2)

Bond strength tests were performed on four concrete composites and two corresponding conventional concrete mixtures. Table 2 shows the mixture constituents used for bond strength testing. The mixtures selected for the bond strength tests were based on the previous studies completed at SIUC. The mixtures designations starting with letter 'D' refer to the mixtures used for drilled shaft project and mixture designation starting with letter 'P' refer to the mixtures used for pre-cast concrete pile project.

Table 2: Mixture Constituents for bond Strength Testing

Mixture Designation	Binders (%)		Fine Aggregates (%)		Remarks
	Portland Cement	PCC Fly Ash	PCC Bottom Ash	Natural Sand	
DCM	100	0	0	100	Control Mix
DB50	100	0	50	50	
DB100	100	0	0	100	
PCM	100	0	0	100	Control Mix
PB50	100	0	50	50	
PB100	100	0	100	0	

Bond strength tests were performed in the laboratory on reinforcing bars embedded in cylindrical concrete samples and in the field on reinforcing bars embedded in trenches filled with concretes. From each batch of concrete, six cylinders, 6 inches in diameter and 12 inch tall, were prepared with three different size reinforcement bars. Two cylinders with each bar size and corresponding embedment length were prepared for each concrete composite for a total of thirty-six cylindrical samples. The reinforcement bar sizes, No.'s 4, 6, and 8, with embedment lengths of 5, 8, and 10 inches, respectively, were used in the cylindrical samples. Using the same concrete batch, one large trench was prepared with three different size reinforcing bars and embedment lengths. The reinforcement bar sizes, No.'s 4, 6, and 8, with embedment lengths of 12, 15, and 18 inches, respectively, were used in the trenches. Figure 8 shows the picture of cylindrical samples prepared for bond strength testing and Figure 9 shows the installation of reinforcing bars in trenches.

Figure 8. Cylindrical sample for bond strength testing of concretes

Figure 9. Construction of trenches for bond strength testing in progress

RESULTS AND DISCUSSION

Strength Testing of Mixtures (Task 1)

Figure 2 shows the comparison of compressive strength of a concrete composite (B100) and conventional concrete (CM) at various curing ages. Figure 10 shows the effect of curing age on the compressive strength of the concrete composite and conventional concrete.

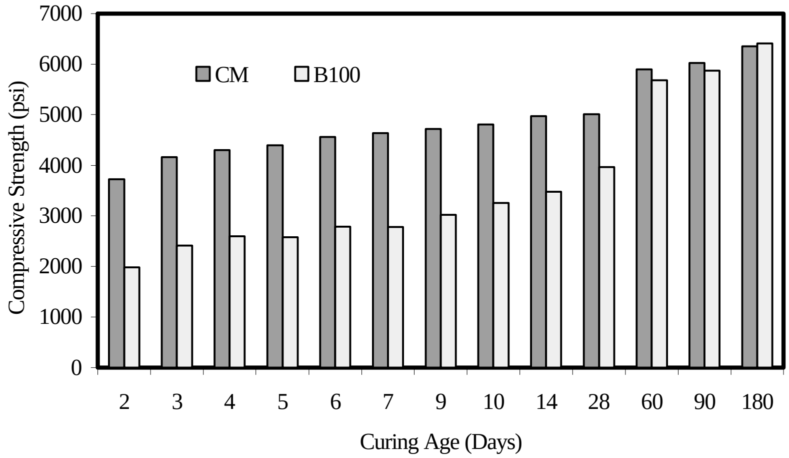


Figure 2. Comparison of compressive strength and influence of curing age on compressive strength of concrete composites

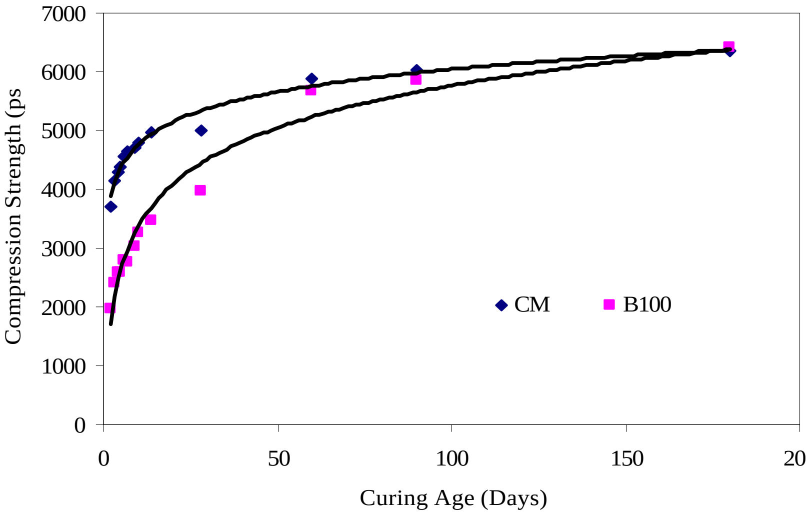


Figure 10. Effect of curing age on compressive strength of concrete composites

From Figures 2 and 10 it is clear that the compressive strength of the composites increased with an increase in curing age. Results also show that the compressive strength of the concrete composite used in the investigation was less than that of conventional concrete up to a curing age of approximately 60 days. However, after 90 days of curing, compressive strength of concrete composite made with Illinois PCC bottom ash was observed to be approximately equal to that of conventional concrete. The compressive strength of the concrete composite tested was greater than the targeted compressive strength of 3,000 psi after 28 days of curing.

Figure 11 shows the comparison of splitting-tensile strength of a concrete composite (B100) and conventional concrete (CM) at various curing ages. From Figure 11 it is clear that the splitting-tensile strength of the composites increased with an increase in curing age. Results also show that the splitting-tensile strength of the concrete composite used in the investigation was less than that of conventional concrete up to curing age of approximately 28 days. However, after 60 days of curing, splitting-tensile strength of concrete composite made with Illinois PCC bottom ash was observed to be slightly greater than that of the conventional concrete.

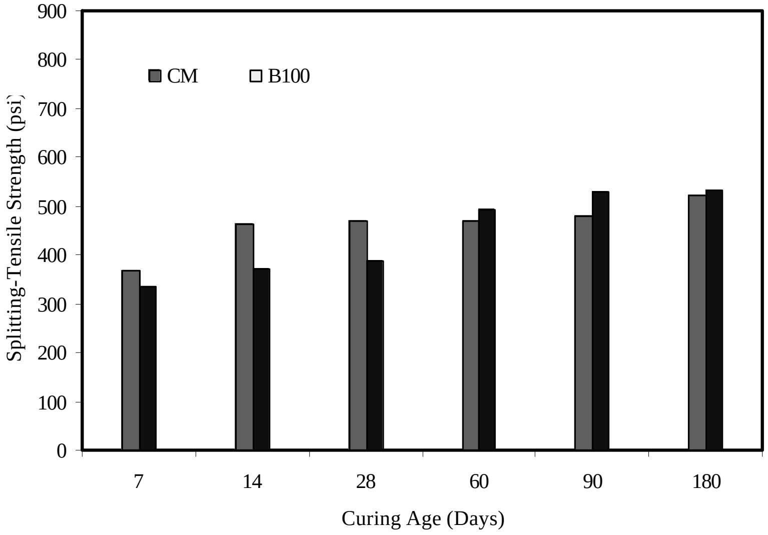


Figure 11. Comparison of splitting-tensile strength and influence of curing age on splitting-tensile strength of concrete composites

Figure 12 shows the comparison of flexural strength of a concrete composite (B100) and conventional concrete (CM) at various curing ages. From Figure 12 it is clear that the flexural strength of the composites increased with an increase in curing age. Results show that the flexural strength of the concrete composite used in the investigation was less than that of conventional concrete at all curing ages. However, the difference in the flexural strength after 28 days of curing is not significant for all practical purposes.

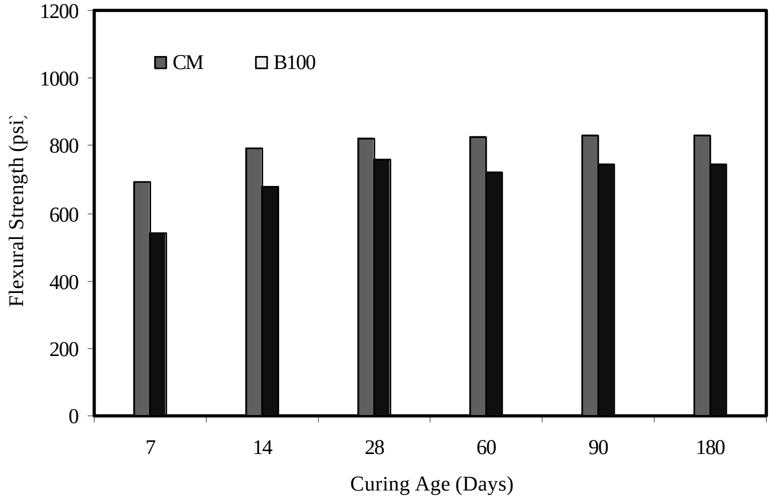


Figure 12. Comparison of flexural strength and influence of curing age on flexural strength of concrete composites

The strength data presented show that the compression strength of the concrete composite tested in this investigation was greater than the specified compression strength of 3,000 psi after 28 days of curing. The project structural engineer also approved the mix design for use in the drilled shafts. However, because of the liability issues, the concrete composite could not be used for the construction of production shafts.

Bond Strength Testing of Concrete Composites (Task 2)

Bond Strength Testing and Results

Bond strength testing was conducted by applying the load to pull the reinforcing bars using hydraulic jacks. Figure 13 shows bond strength testing of cylindrical samples in progress and Figure 14 shows bond strength testing of concrete in field trenches.

Figure 13. Bond strength of cylindrical samples in progress

Figure 14. Bond strength testing of concrete in field trenches in progress

Figure 3 shows the test results from cylindrical samples. It is clear from Figure 3 that in general, the bond strength of concrete composites made with Illinois PCC dry bottom ash is similar to that of conventional concrete. Figure 15 shows results from bond strength testing of concretes in field trenches. From the results shown in Figure 15, in general, the bond strength of concrete composites made with Illinois PCC dry bottom ash is similar to that of conventional concrete. Results from test on conventional concrete, DCM, appear to be anomalous.

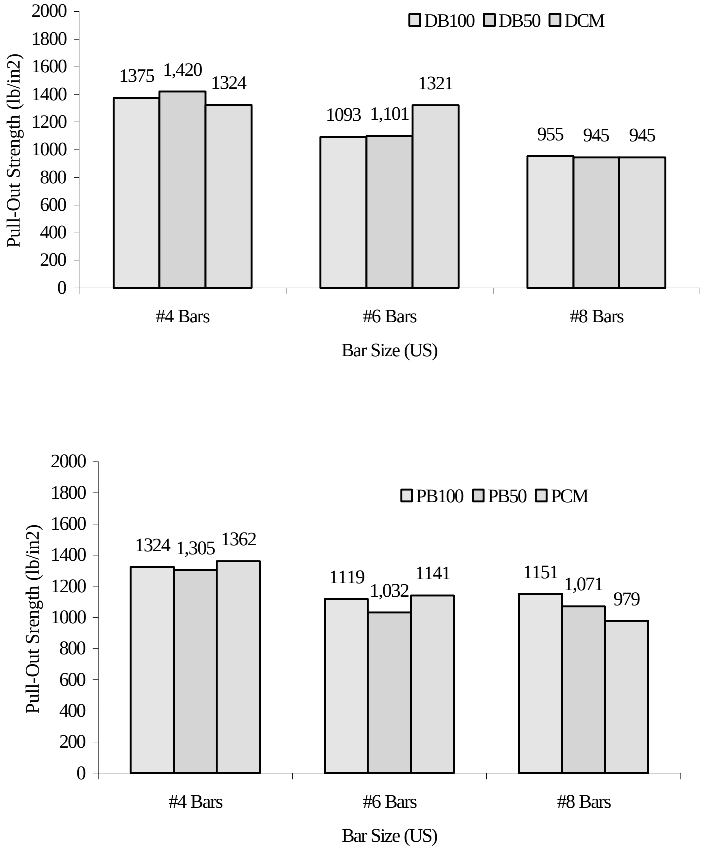
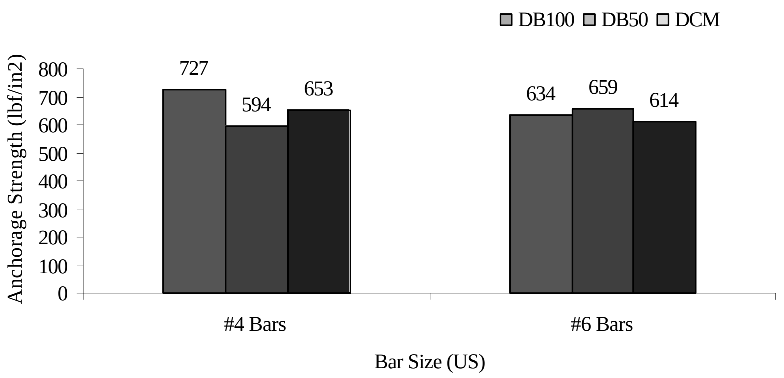


Figure 3. Bond strength test results from cylindrical samples



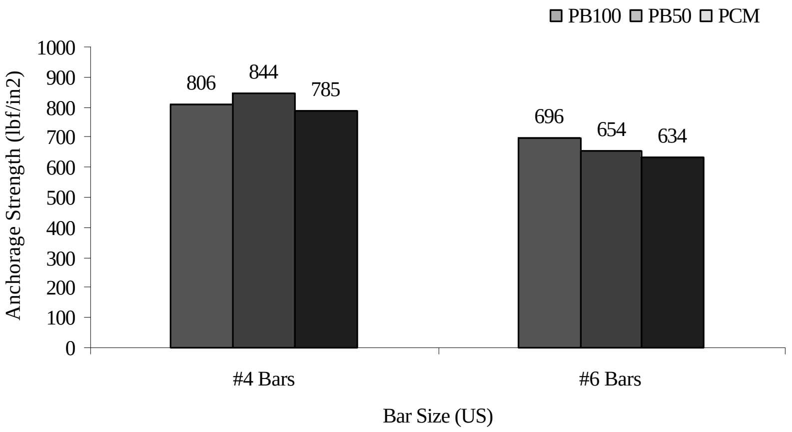


Figure 15 Bond strength results from concretes in field trenches

CONCLUSIONS AND RECOMMENDATIONS

Based on the laboratory tests and field tests performed on the samples and drilled shafts prepared using Illinois PCC bottom ash and an equivalent conventional concrete, it was concluded that the performance of drilled shafts made with concrete composites containing Illinois PCC bottom ash was similar to the performance of drilled shaft constructed using conventional concrete. The results from bond strength testing of concrete composites also showed that the bond strength of concrete composites containing Illinois PCC bottom ash was similar to that of an equivalent conventional concrete. The concrete composite tested in this investigation could not be used in the production shafts because of the liability issues.

DISCLAIMER STATEMENT

This report was prepared by Sanjeev Kumar, Southern Illinois University - Carbondale with support, in part by grants made possible by the Illinois Department of Commerce and Community Affairs through the office of Coal Development and the Illinois Clean Coal Institute. Neither the authors nor any of its subcontractors nor the Illinois Department of Commerce and Community Affairs, Office of Coal Development, Illinois Clean Coal Institute, nor any person acting on behalf of either:

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