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USE OF PONDED ASH AND FINE CRUSHED SAND FOR FLOWABLE SLURRY

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ABSTRACT

The American Coal Ash Association has reported that over 11 million tons of pondered coal fly ash and bottom ash are generated each year (1999). Of the pondered materials, only 0.2% have been used in flowable fill applications. The source of coal ash utilized for this project was a Class F coal ash from Illinois that was wet collected and pondered. A combination of fly ash and bottom ash were utilized for the CLSM manufactured at the facilities of a ready-mixed concrete producer. Crushed sand, obtained from a limestone quarry, was also used for the CLSM. The crushed fine sand is a by-product of the quarry process and typically does not have a significant demand for use. It is typically landfilled. A typical quarry can generate thousands of tons of crushed fine sand per year. A total of five mixtures were developed in the laboratory consisting of different combinations of pondered coal ash and fine crushed sand, from 0% coal ash and 100% fine sand, to 100% coal ash and 0% fine sand. Each of the mixtures were tested for compressive strength, water permeability, and setting and hardening characteristics following procedures specified by the Illinois Department of Transportation. Based upon the laboratory results, these five mixtures were modified for prototype-scale production at the facilities of a ready-mixed concrete producer. Compressive strength test specimens were made at the time of placement of the field mixtures to verify results obtained from the laboratory mixtures. Results of the project show that CLSM can be successfully manufactured using two by-product materials, pondered coal ash and fine crushed sand.

INTRODUCTION

The American Coal Ash Association has reported that over 11 million tons of ponded coal fly ash and bottom ash are generated each year (1999). Of the ponded materials, only 0.2% have been used in flowable fill applications. The source of coal ash utilized for this project was a Class F coal ash from Illinois that was wet collected and ponded. Illinois coal, when it is burned in conventional boilers, produces Class F, low-lime, fly ash. In general, utilization rate of Class F fly ash in U.S.A. is substantially lower relative to Class C, high-lime, fly ash. This is partly due to the perceived lower quality of Class F fly ash compared to Class C, and greater variation in its properties, especially for Class F fly ash generated from older power plants. Also, there is a significant lack of commercial products that use high-volumes of Class F fly ash; and, there is even a greater lack of use for ash that is wet collected and sluiced (ponded ash). Due to shrinking landfill space, to address environmental concerns, and due to increased public awareness and debate, it has become mandatory to find practical solutions to this "ash problem".

LITERATURE REVIEW

A great deal of research work has been reported concerning utilizations of conventional coal combustion by-products [1-16]¹. In 1998, Naik and Singh [16] summarized various applications of fly ash generated from conventional and clean coal technologies. Uses of coal combustion by-products can be categorized into three classes: high-volume applications; medium-volume applications; and low-volume applications. A typical and very successful high-volume application of coal ash is in controlled low-strength materials (CLSM). Class F and C coal fly ash has been used for CLSM [17-24]. Naik, et al. reported to ACI in 1989 (later published by ACI in 1990) work done in Milwaukee area for about the last 20 years [17].

CLSM can be defined as a cementitious material which is in a flowable state, easy to place, and has a specified compressive strength of 1,200 psi or less at 28 days [17]. It is used for low-strength, primarily non-structural, applications. In accordance with Naik et. al, in most cases, its desired strength is similar to the surrounding soil. The main uses of this material are for backfilling trenches containing ducts, pipes, etc., around manholes and similar excavations in streets, or backfilling of foundation excavations. It has also been used to backfill mine excavations, abandoned tunnels, sewers, and other underground facilities. In the last five years or so, the use of CLSM is increasing for construction of roadways, highways, and airfield pavements. Naik, et al. [17-24] have discussed results of tests performed on Class F and C fly ash CLSM. Based on these results it was concluded that a cement content of about 75 (± 25) lb/yd³ is necessary to produce compressive strength between 50 and 150 psi at the age of 28 days. The flowability of CLSM slurry can be varied by increasing the amount of water added. Naik, et al. [18-21] also developed mixture proportions for low-strength concrete slurry as a controlled low-strength material (CLSM) incorporating ASTM Class F and C fly ash. Compressive strength of these mixtures was varied from 500 psi to 1500 psi with both low- and high-slump. They concluded that the mixtures developed for their projects could be used as the basis for selecting

¹See corresponding reference number in Appendix A: List of References.

mixture proportions of both low- and high-slump flowable fly ash slurry when these materials are utilized.

In 1991, Naik, et al. [20, 21] reported on two different ash materials, ASTM Class F and Class C fly ash, as the primary material in developing flowable CLSM slurry mixture proportions. Based on the information obtained as part of their study, it was concluded that a high-volume fly ash CLSM could be produced with either ASTM Class F or Class C fly ash. The CLSM was found to perform well and it was concluded that a high-volume ASTM Class F fly ash CLSM could be successfully produced and used in the construction industry. Ramme, et al. [22] studied the application of high-volume fly ash CLSM for backfilling trenches and filling underground facilities. The objective of the study was to expand the utilization of fly ash produced by Wisconsin Electric Power Co. Initially a laboratory and later a field study was conducted using CLSM. CLSM was evaluated for physical, mechanical, and chemical properties, electrical resistivity, polyethylene plastics compatibility, etc. The results indicated that the CLSM could be successfully utilized as a backfill material for trenches. Corrosion potential and the effect on polyethylene pipes were found to be within normally accepted limits. CLSM was also recommended for backfilling around underground power lines where high thermal conductivity, high density, and low porosity of the CLSM material was desirable.

Naik and Singh [23] in 1992-1994 studied the effects of incorporating fly ash as well as used foundry sand (used molding sand for metal castings) in CLSM. Leaching of the CLSM materials was evaluated along with other physical, mechanical, and chemical properties. Leaching analysis of CLSM made with one of the sources of fly ash was found to meet drinking water standards [24]. The chemical composition of the leachate was dependent on the source of the coal ash. An extensive laboratory evaluation of the CLSM material was conducted which included compressive strength, permeability, shrinkage, chemical composition, settlement, setting and hardening, and chemical leachate analysis [23, 24]. They found that foundry sand could be used in conjunction with fly ash to make CLSM. Currently used foundry sand and/or coal fly ash are being specified for construction projects in Wisconsin.

Krell [25] discussed using fly ash CLSM as a backfill in flowing water in Michigan, at a depth of about 20 feet. Class F fly ash CLSM was placed at a relatively stiff consistency (slump of about 6 inches). The mixture contained: 1800 lbs of dry fly Class F ash; 90 lbs of portland cement; and about 670 lbs. of water per cu. yd. of CLSM. It was reported that this material was easily placed under water. He also observed that this material can support the weight of a loaded truck after 24 hours. Krell also performed tests for unconfined compressive strength for the CLSM containing cement, Class F fly ash, and water. He obtained a value of about 100 psi. This was better than any other conventional material for backfilling operations. The modulus of rupture for this material was found to be almost equal to its compressive strength. The CLSM material was also tested for erosion. The material was placed in a tank in which water was continuously poured over it. The aim was to study how much material would be eroded and how it will affect the water quality. Krell showed that CLSM performed better than any other conventional material. Only clean rock fill would be better than the fly ash CLSM in this respect. Larsen [26] discussed various instances where the CLSM material was successfully used. Iowa-DOT filled two-200 gal. and one-1000 gal. abandoned fuel tanks with flowable fly ash CLSM. This project was

completed for \$1,140. Removing the tanks was estimated to cost \$8,000. In accordance with Federal and State rules, filling in-place tanks with inert solid material is an alternative to tank removal. Throughout the USA this remains a significant market for CLSM. Several counties in Iowa placed culverts on CLSM bedding [26]. This prevented water from getting to the bottom of the culvert pipe and/or the bedding, and eroding the pipe support. Excavations necessary for placing pipe lines were made smaller when flowable fly ash CLSM was to be used as a backfill, because it is self compacting. CLSM was also used for erosion prevention. A V-shaped drainage ditch for a parking lot in Iowa was lined with riprap (stones, blocks, concrete, or other protective covering material to prevent erosion and scour by water flow) and loose rock. But due to high-volume of storm water run off, the material in the riprap was washed away. When this was rebuilt, the ditch was relined with riprap; and, then fly ash CLSM slurry was placed through the riprap and in the offset parking area to a depth of 4 inches. The CLSM was also placed over the riprap as a capping material. The overall performance of the CLSM was considered very satisfactory and cost-effective. Voids were created under a bridge pier in St. Paul, Minnesota, and erosion was caused by wash outs. A four-inch pipe was positioned down each pier to the bottom of the bridge pier footing. Riprap was placed into the void around the pipe. Flowable fly ash CLSM slurry was then pumped into the void and through the riprap until it came out into the current. Subsequent sounding test showed that the support for these footings remained very solid.

Edil, et al. [27] studied the feasibility of using fly ash either by itself or mixed with sand, as a construction material for waste containment liners and impermeable covers. They noted that the liners can be constructed from pozzolanic ash with or without sand mixtures to meet the usual requirement for the permeability of 10^{-7} cm/s or less for liners. They also investigated the effects of long-term permeation of inorganic leachates solutions on performance of such liner materials. Comparing of leachate from specimens with two different permeabilities showed that calcium and sulfur concentrations were lower when permeability was lower. Sodium, chloride, boron, cadmium, and pH data showed no significant changes and zinc concentrations were higher with lower permeabilities. It was, therefore, concluded that to have a low permeability coal ash liner material, with low level of leachates, major variables were compaction effort and moisture content affecting the permeability of the fly ash liner material and the type and percentage of fly ash used.

Naik, et al. [28-35] has continued to demonstrate the feasibility of using by-product materials in CLSM. CLSM has been developed using fluidized bed boiler ash [28], used foundry sand [29, 30], excavated soil [33], wood ash [34], and high-carbon ash [35]. These CLSM materials developed meet performance requirements such as excavatability, cohesiveness, permeability, and environmental considerations. A very important conclusion of these reported projects [28-35] was that coal ash was necessary in CLSM when other recyclable materials were used. State-of-the-art reports presented by Ramme and Naik [31, 32] emphasize the use of coal ash not meeting ASTM C 618 in CLSM applications.

CLSM MIXTURE REQUIREMENTS

The Illinois Department of Transportation (IDOT) specifies three different standard mixture proportions for CLSM: Mixture 1 contains 50 lb/yd³ of cement, 125 lb/yd³ fly ash, 2900 lb/yd³ fine aggregate, and 50 to 65 gal./yd³ of water; Mixture 2 contains no fly ash, but has 125 lb/yd³ of cement, 2500 lb/yd³ of fine aggregate, 35 to 50 gal/yd³ of water and air entrained to contain between 15 and 25% air content. Mixture 3 contains 40 lb/yd³ of cement, 125 lb/yd³ of fly ash, 2500 lb/yd³ of fine aggregate, and is also air entrained to contain 15 to 25% air content. Alternate mixture proportions are also allowed to be submitted to IDOT provided that they meet the following mixture performance criteria: flow greater or equal to seven inches, air content between 0 and 25%, dynamic cone penetrometer at the three-day age less than 1.5 inches, and compressive strength at 28 and 180 days greater than 30 psi and less than 125 psi. Alternate mixture proportions submitted to IDOT must also specify the source of all materials; gradation of fine aggregate; volumes, specific gravity, unit weights, etc. used to establish mixture proportions; type and dosage of admixtures; flow and air content; and compressive strength at 28 and 180 days. These specifications are applicable to projects funded by IDOT, but other CLSM performance requirements may be specified depending on the specific application.

PROCEDURES

Materials

Type I portland cement (ASTM C 150) was used in this work. An ASTM Class F fly ash from Illinois from a wet collection process was also used for the current study. The as-received moisture content of Class F fly ash ranged between 10 and 20 percent. The fine aggregate used for this project was a fine crushed sand obtained from a quarry. The crushed fine sand is a by-product of the quarry process and typically does not have a significant demand for use, and therefore, is typically landfilled.

Material Characterization

Materials used for producing flowable slurry (CLSM) used for this project were tested in accordance with standard ASTM test methods. ASTM test procedures for fly ash and cement are given in Reference 36. ASTM test procedures for fine aggregate are given in Reference 37. The Illinois coal fly ash (requirements per ASTM C 618) was characterized for chemical properties including oxides, elements, mineralogy, and the following physical tests: fineness (ASTM C 430), strength activity index with cement (ASTM C 109), water requirement (ASTM C 109), autoclave expansion (ASTM C 151), and specific gravity (ASTM C 188). Fine crushed sand was tested per ASTM C 33 requirements for the following physical properties: unit weight (ASTM C 29), specific gravity and absorption (ASTM C 128), fineness (ASTM C 136), and material finer than #200 sieve (ASTM C 117).

Manufacturing of Laboratory Mixtures

Prior to prototype manufacturing, laboratory mixtures were prepared to establish preliminary mixture proportions and to determine performance of the mixtures prior to introducing the product manufacturer to CLSM manufacturing technology. Similar laboratory mixture procedures were followed to those outlined in ACI 229R for mixing CLSM in a ready-mixed concrete truck mixer. First, approximately 70 to 80 percent of the water required was added to

the mixer. Subsequently, approximately half of the fine aggregate was added to the mixer, mixed for one minute, then all of the cement and half of the ash was added to the mixer, again mixed for one minute, then the remaining ash was added. Finally, with continued mixing, the remaining fine aggregate with the remaining water was added. If during the mixing process, the mixture appeared to be dry, more water was added. After all materials were added, the mixture was mixed for minimum three minutes.

Manufacturing of CLSM Mixtures for Prototype-Scale Production

All ingredients were batched and mixed at a ready-mixed concrete plant. All CLSM was manufactured in accordance with the recommendations of ACI 229R. For production of prototype-scale mixtures, fine crushed sand, cement, and water were batched and added into a conventional ready-mixed concrete truck mixer. Ash was weighed separately for each ready-mixed truckload via a portable hopper typically used for portable batch plant facilities.

For prototype mixtures, CLSM was transported to the test location for fresh CLSM testing and casting of test specimens. Additional water was added in the mixture as needed for achieving the desired level of workability (flow). Whenever any additional water was added, the CLSM mixture was mixed at a high mixing speed for an additional minimum three minutes.

Testing and Specimen Preparation

Fresh CLSM properties such as air content (ASTM D 6023), flow (ASTM D 6103), unit weight (ASTM D 6023), and temperature (ASTM C 1064) were measured and recorded. Air temperature was also measured and recorded. Standard ASTM test procedures for fresh CLSM properties were followed for these tests [37]. The amount of bleedwater and the level of the solids (settlement) in the 6x12-inch cylinders were also recorded.

Test specimens were prepared for each CLSM mixture for compressive strength and permeability testing. All test specimens were cast in accordance with ASTM D 4832. These specimens were typically initially cured for three to seven days in their molds at about $75^{\circ} \pm 10^{\circ}$ F at the location of the specimen preparations at the manufacturing facilities. They were then brought to the lab for further testing. For continued curing, these specimens were removed from the molds and placed in a standard moist-curing room, maintained at 100% R.H. and $74 \pm 3^{\circ}$ F, starting at the age of approximately seven days.

Setting and hardening of CLSM was measured following the State of Illinois Department of Transportation (IDOT) specifications. IDOT specifies the use of a dynamic cone penetrometer (DCP) following Illinois Test Procedure 401. The DCP consists of a 17.6 lb hammer dropped 22.6 inches, which drives a conical end into the CLSM. The total number of blows are recorded for each 6-inch depth. This is then converted to an equivalent number of blows per inch. For laboratory mixtures, the DCP test was evaluated for 6x12-inch CLSM cylinders which were kept in the mold during the test to simulate confining pressure from surrounding CLSM that might be placed at a construction site.

Properties of hardened CLSM mixtures were evaluated as a function of age. Standard unconfined compressive strength test (ASTM D 4832), and water permeability test (ASTM D 5080) using

the falling head, constant tailwater pressure method, were conducted.

RESULTS

Materials used for manufacturing CLSM slurry were tested and evaluated for its physical, mechanical, and chemical characteristics. Testing was carried out using standard ASTM, ACI, or US-EPA test methods as required. Fine crushed sand (FCS) was used for the CLSM mixtures as a source of fine aggregate. FCS met ASTM C 33 requirements with the exception of the material passing No. 100 sieve, Tables 1 to 3, 5, and 6. This finer material, although not normally used in structural concrete, would be beneficial when used in CLSM. The finer materials assist the flow characteristics of the material. Characteristics evaluated of the wet collected Class F ash (WF) included: gradation, strength development with cement, oxides, and mineralogy, Tables 4 to 6. These properties were used in determining mixture proportions developed for this project. The ash used for the project, a wet collected and ponded Class F fly ash (WF), was also characterized per ASTM C 618 requirements. The ash met ASTM requirements for Class F fly ash with the exception of loss on ignition, and the sum of ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$).

Table 1: Sieve Analysis (ASTM C 136)

Sieve Analysis		
Sieve Size	% Passing*	ASTM C 33 % Passing for Sand
	FCS (Fine Crushed Sand)	
3/8" (9.5 mm)	100	100
#4 (4.75 mm)	99.7	95 to 100
#8 (2.36 mm)	84.6	80 to 100
#16 (1.18 mm)	55.0	50 to 85
#30 (600 μm^{**})	33.9	25 to 60
#50 (300 μm^{**})	24.0	10 to 30
#100 (150 μm^{**})	16.9	2 to 10

Table 2: Unit Weight and Voids (ASTM C 29)

Source	Unit Weight (lbs/ft ³)	Voids (%)
Fine Crushed Sand	88.9	48.1

Table 3: Specific Gravity (ASTM C 128)

Fine Aggregate Source	Bulk Specific Gravity	Bulk Specific Gravity (SSD Basis)	Apparent Specific Gravity
Fine Crushed Sand (Laboratory and Field Mixtures)	2.74	2.78	2.74

Table 4: Specific Gravity of Fly Ash (ASTM C 311/C 188)

Fly Ash Source	Specific Gravity	
	Actual	Average
Ponded Coal Ash	2.46	2.45
	2.46	
	2.41	

Table 5: Chemical Analysis

Analysis Parameter	Material		ASTM C 618 Requirements		
	Fine Crushed Sand	Ponded Coal Ash	Class N	Class C	Class F
Silicon Dioxide, SiO ₂	3.9	26.6	--	--	--
Aluminum Oxide, Al ₂ O ₃	1.5	12.0	--	--	--
Iron Oxide, Fe ₂ O ₃	0.8	18.5	--	--	--
SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃	6.2	57.1	70.0, Min.	50.0, Min.	70.0, Min.
Calcium Oxide, CaO	31.3	5.6	--	--	--
Magnesium Oxide, MgO	22.3	1.2	--	--	--
Titanium Oxide, TiO ₂	0.0	0.5	--	--	--
Potassium Oxide, K ₂ O	0.6	1.1	--	--	--
Sodium Oxide, Na ₂ O	0.0	0.6	--	--	--
Sulfate, SO ₃	0.0	1.0	4.0, Max.	5.0, Max.	5.0, Max.
Loss on Ignition, LOI (@ 750 C)	42.7	34.1	10.0, Max.*	6.0, Max.*	6.0, Max.*
Moisture Content	0.0	1.6	3.0, Max.	3.0, Max.	3.0, Max.
Available Alkali, Na ₂ O Equivalent (ASTM C-311)	NA	1.1	1.5, Max.**	1.5, Max.**	1.5, Max.**

* Under certain circumstances, up to 12.0% max. LOI may be allowed.

** Optional. Required for ASR Minimization.

Table 6: Mineralogy

MINERALOGY (% by Weight)		
Analysis Parameter	Fine Crushed Sand	Ponded Coal Ash
Amorphous	--	74.4
Dolomite, $\text{CaMg}(\text{CO}_3)_2$	98.0	--
Hematite, Fe_2O_3	--	4.0
Magnetite, Fe_3O_4	--	4.7
Mullite, $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$	--	7.0
Quartz, SiO_2	2.0	3.9

In order to establish performance characteristics of CLSM prior to prototype-scale production, laboratory mixtures were produced. Fine crushed sand (FCS) was used as the fine aggregate. A total of five mixtures were produced in the laboratory (Table 7). Ponded ash content of the mixtures, expressed as a percentage of total fines (fly ash and crushed fine sand), varied from 100% (Mixture A1), to 0% (Mixture A5). Target values for ash content of the remaining mixtures were 67% for Mixture A2, 50% for Mixture A3, and 33% for Mixture A4. Flow of the mixtures was maintained at about ten inches. Water requirement of the mixtures decreased with increased fine crushed sand content, 919 lb/yd³ of water for Mixture A1 (100% ash) to 598 lb/yd³ for Mixture A5 (0% ash). As expected, density of the CLSM also increased as the amount of fine crushed sand increased: 90 lb/ft³ to 134 lb/ft³ for mixtures A1 to A5, respectively. Initially, at the age of 3 days, compressive strength of the mixtures varied between 20 to 35 psi. The strength of the mixtures was evaluated at the ages of 3, 7, 28, 56, and 91 days (Table 8). Compressive strength of the mixtures generally increased with age.

Dynamic cone penetrometer (DCP) values (Fig. 1), for all mixtures were one inch/blow or less at the age of 24 hours. IDOT CLSM specifications indicate that 1.5-in/blow or less as adequate to support construction loading. Settlement of the mixtures (Fig. 2) reveal that increasing fine crushed sand content combined with reduced fly ash content generally increased the settlement of the mixtures because of the higher specific gravity of the sand versus that for the fly ash. Settlement of Mixture A5 without ash was 0.25 inch per foot height of CLSM mixture. Settlement of the mixtures improved significantly with 35% ash content (Mixture A4) to less than 0.15 in/ft.

Water permeability of all Series 1A laboratory mixtures were very low, 2.9×10^{-6} cm/sec to 43×10^{-6} cm/sec (Table 9). At the age of 132 days, impermeability increased. The increase in impermeability is due to decreased void structure within the CLSM due to hydration of cement and/or pozzolonic reaction of the Illinois coal fly ash used.

Table 7: CLSM Laboratory Mixture Proportions

Mixture No.	A1	A2	A3	A4	A5
Ponded Ash Content, A/(A+R), (%)	100	67	53	35	0
Fine Crushed Sand Content, R/(A+R), (%)	0	33	47	65	100
Cement, (lb/yd ³)	97	92	94	90	97
Ponded Ash, Dry Wt., A, (lb/yd ³), A	1425	1140	1025	740	0
Fine Aggregate, Dry Wt., (lb/yd ³), R	0	560	905	1365	2935
Water, W (lb/yd ³)	919	860	766	723	598
Flow (in)	10 ¼	10	10 ½	10 ½	10
Air Content (%)	3.6	4.0	3.4	2.3	1.4
Air Temperature (°F)	73	75	73	75	72
Slurry Temperature (°F)	67	74	66	73	68
Density of Fresh Slurry (lb/ft ³)	90.4	98.2	103.4	108.2	134.4
Yield (ft ³)	5.7	6.0	5.9	6.1	5.7

Table 8: CLSM Compressive Strength of Laboratory CLSM Mixtures

Mixture Number	Fly Ash Content, %	FCS Content, %	Compressive Strength, psi									
			Test Age									
			3-days		7-days		28-days		56-days		91-days	
			Act.	Ave.	Act.	Ave.	Act.	Ave.	Act.	Ave.	Act.	Ave.
A1	100	0	20	20	35	25	50	50	55	55	55	65
			20		30		50		55		70	
			20		15		50		50		70	
A2	67	33	20	25	45	40	65	65	80	80	85	85
			25		35		65		70		90	
			25		35		70		85		75	
A3	53	47	35	30	40	40	75	75	95	95	110	110
			30		45		75		100		115	
			30		35		70		95		105	
A4	35	65	20	20	35	30	65	60	60	60	70	70
			20		30		55		55		65	
			20		30		65		70		70	
A5	0	100	30	35	40	40	50	65	40	40	50	50
			35		40		75		45		45	
			35		45		65		35		50	

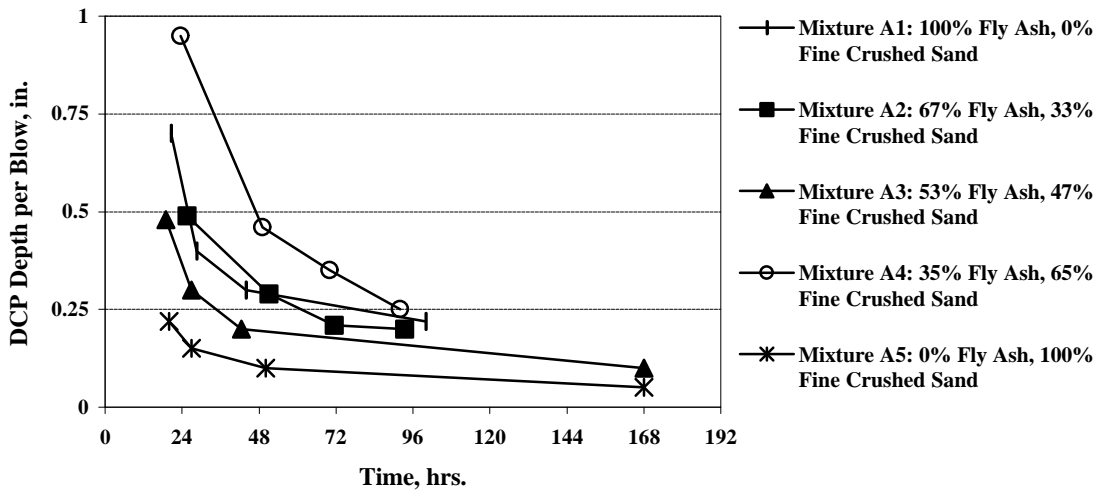


Fig. 1 - Setting of Series 1B CLSM Laboratory Mixtures

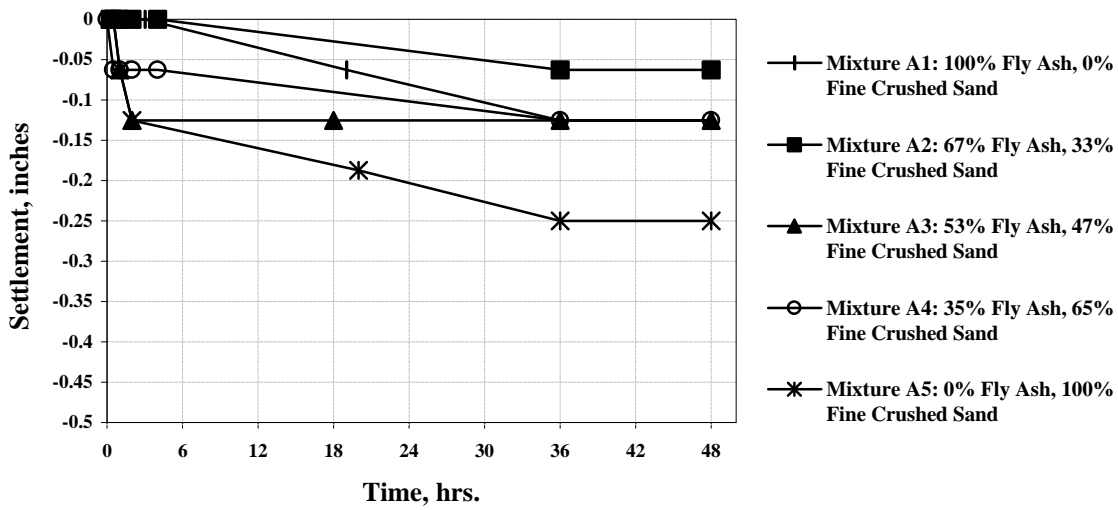


Fig. 2 - Settlement of Series 1B CLSM Laboratory Mixtures

Table 9: Water Permeability of Laboratory Mixtures

Mixture Number	Fly Ash Content, %	FCS Content, %	Permeability (cm/sec)	
			67-day age	132-day age
A1	100	0	10.6×10^{-6}	7.2×10^{-6}
A2	67	33	43.0×10^{-6}	41.4×10^{-6}
A3	53	47	2.86×10^{-6}	2.51×10^{-6}
A4	35	65	7.36×10^{-6}	5.88×10^{-6}
A5	0	100	34.0×10^{-6}	27.2×10^{-6}

CLSM Mixtures for Prototype-Scale Production and Testing

Prototype-scale production of CLSM (Series F1) was conducted at the facilities of a ready-mixed concrete producer. Production consisted of eight CLSM mixtures using a combination of ponded coal ash and fine crushed sand as fine aggregate. The purpose of the prototype production was to familiarize the producers with the handling of ponded ash from Illinois coal for CLSM and to obtain test data from these production mixtures. The prototype production mixtures, Series F1, consisted of five mixtures, Mixtures 1 to 5, containing 100%, 64%, 47%, 23%, and 0% fly ash, respectively (Table 10). Mixtures 1, 2, and 3 were mixed with very high flows, 24 inches. Mixture 4, 23% fly ash, had a higher flow than a similar laboratory mixture, 15-1/2 inches versus 10-1/2 inches. Mixture 4 also had approximately 25 lb/yd³ higher cement content than the laboratory mixtures. Mixture proportions of Mixture 5 was close to the corresponding laboratory mixture, with the exception of a lower flow and a slightly higher cement content. The lower flow and higher cement content was expected to increase the compressive strength of the mixture. Compressive strength of prototype CLSM Series F1 mixtures were measured at 21, 28, and 160 days (Table 11). Mixtures 1, 2, and 3, which had a very high flow, achieved compressive strength of 25 psi at the age of 28 days, and 45 to 55 psi at the 160-day age. These data would indicate that these CLSM mixtures, when produced at very high flows, would still achieve compressive strength that would be quite satisfactory to support construction loading. Compressive strength of Mixture 4 was high at the age of 160 days, 205 psi, in accordance with IDOT specifications. CLSM with this compressive strength would be difficult to excavate without the use of a backhoe or jackhammer. This CLSM would be suitable for applications where the material would not be expected to be excavated in the future, such as under slabs and roadway pavements. If future excavation is expected, the cement content of the mixture should be reduced. Since several of Series F1 mixtures fell outside of the expected range of laboratory mixtures, three additional prototype-scale mixtures were produced, Series F1A (Table 12).

Series F1A Mixtures 6, 7 and 8 contained 68%, 51%, and 33% fly ash, respectively (Table 12). Approximately three cu.yd. batches were produced for each of these new prototype-scale mixtures. Similar to the other CLSM mixtures, unit weight of these mixtures increased as the amount of fine crushed sand increased. Flow of the three Series F1A mixtures were between 10-1/2 and 11-1/2 inches, closer to the flow obtained from the laboratory mixtures. Cement content of the CLSM mixtures was also approximately the same, 97 to 99 lb/yd³, as equivalent laboratory mixtures. Compressive strength of the Series F1A mixtures was obtained at the age of 7, 28, and 160 days (Table 13). Compressive strength of Mixtures 6 and 7 were approximately the same, 25 to 30 psi at the age of 7 days, 50 psi at 28 days, and 90 to 100 psi at 160 days. Both of these CLSM mixtures can be expected to be excavatable. Mixture 8, 33% fly ash and 67% fine crushed sand attained a slightly higher compressive strength compared with Mixtures 6 and 7. Compressive strength was 35 psi at the age of 7 days, 75 psi at 28 days, and 160 psi at 160 days. To achieve an excavatable mixture, the cement content of Mixture 8 should be decreased from 98 lb/yd³ to approximately 75 lb/yd³ or less.

Table 10: CLSM Field Mixture Proportions – Series F1

Mixture No.	1	2	3	4	5
Fly Ash Content, A/(A+R), (%)	100	64	47	23	0
Fine Crushed Sand Content, R/(A+R), (%)	0	36	53	77	100
Cement, (lb/yd ³), C	86	86	99	122	106
Fly Ash, Dry Wt., A, (lb/yd ³), A	815	730	700	680	0
Fine Aggregate, Dry Wt., (lb/yd ³), R	0	405	780	1520	3195
Water, W (lb/yd ³)	1245	1055	970	820	535
Flow (in)	24	24	24	15-1/2	6
Fresh CLSM Density (lb/ft ³)	79.7	84.4	94.4	111.8	138.0
Settlement, (in)	1-3/8	¾	1/4	0	0

Table 11: CLSM Compressive Strength of Field CLSM Mixtures – Series F1

Mixture Number	Fly Ash Content, %	Fine Crushed Sand Content, %	Compressive Strength, psi					
			Test Age					
			21-days		28-days		160-day	
			Act.	Ave	Act.	Ave	Act.	Ave.
1	100	0	15	15	20	25	45	45
			15		25		50	
			20		25		40	
2	64	36	20	20	20	25	60	55
			25		25		70	
			20		30		40	
3	47	53	30	35	40	40	95	80
			35		40		65	
			35		35		85	
4	23	77	140	115	120	130	225	205
			105		110		195	
			95		155		195	
5	0	100	90	85	85	95	105	95
			85		100		100	
			85		95		85	

Table 12: CLSM Field Mixture Proportions – Series F1A

Mixture No.	6	7	8
Fly Ash Content, A/(A+R), (%)	68	51	33
Fine Crushed Sand Content, R/(A+R), (%)	32	49	67
Cement, (lb/yd ³), C	99	97	98
Fly Ash, Dry Wt., A, (lb/yd ³), A	1160	975	730
Fine Aggregate, Dry Wt., (lb/yd ³), R	570	960	1440
Water, W (lb/yd ³)	875	800	740
Flow (in)	10- ½	10- ½	11- ½
Density of Fresh Slurry (lb/ft ³)	100.0	104.4	111.2
Yield (yd ³)	2.8	2.8	2.9

Table 13: CLSM Compressive Strength of Field CLSM Mixtures – Series F1A

Mixture Number	Fly Ash Content, %	Fine Crushed Sand Content, %	Compressive Strength, psi					
			Test Age					
			7-days		28-days		160-day	
			Act.	Ave	Act.	Ave	Act.	Ave.
6	68	32	25	25	45	50	100	100
			25		50		120	
			25		55		85	
7	51	49	25	30	45	50	90	90
			30		50		95	
			30		50		80	
8	33	67	35	35	75	75	175	160
			40		75		160	
			35		75		145	

SUMMARY AND CONCLUSIONS

CLSM was initially batched in the laboratory and were composed of a combination of fine crushed sand, ponded coal ash obtained from the combustion of coal from Illinois, and cement. The coal ash and fine crushed sand content was varied for the mixtures from 0% Illinois coal ash and 100% fine crushed sand, to 100% coal ash without sand. Laboratory mixtures were evaluated for fresh CLSM properties as well as compressive strength and water permeability. The laboratory mixtures were then used as the basis for mixture proportions used for field manufacturing. Field mixtures were manufactured at the facilities of ready-mixed concrete producer. The CLSM test mixtures manufactured generated the necessary experimental and production data to optimize CLSM mixture proportions for commercial production.

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