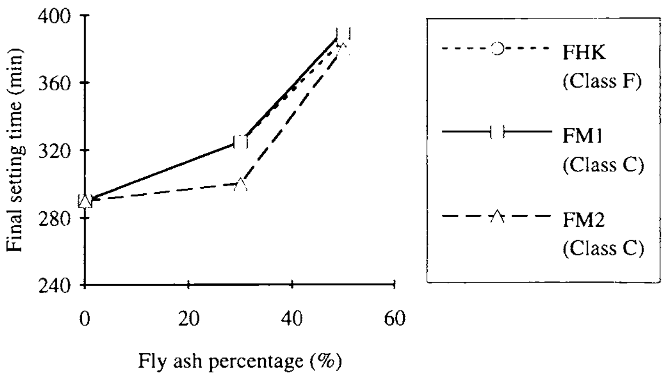

Fig. 12—Results of final setting time of paste

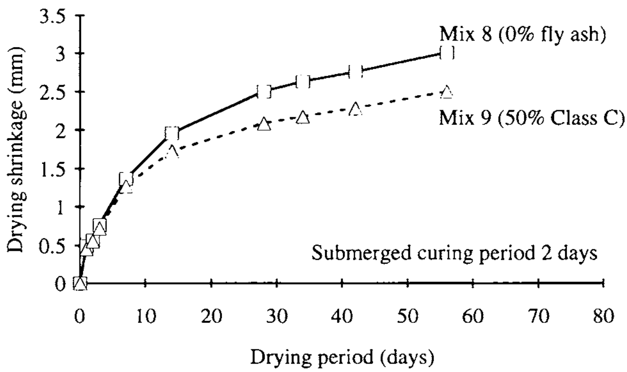

Fig. 13—Drying shrinkage of pastes with and without Class C fly ash (specimens with 2 days' submerged curing condition)

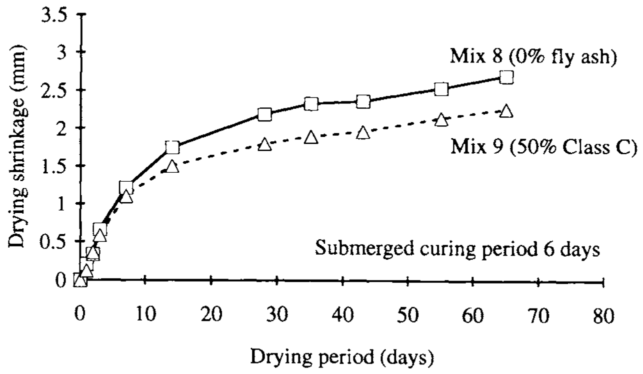

Fig. 14—Drying shrinkage of pastes with and without Class C fly ash (specimens with 6 days' submerged curing condition)

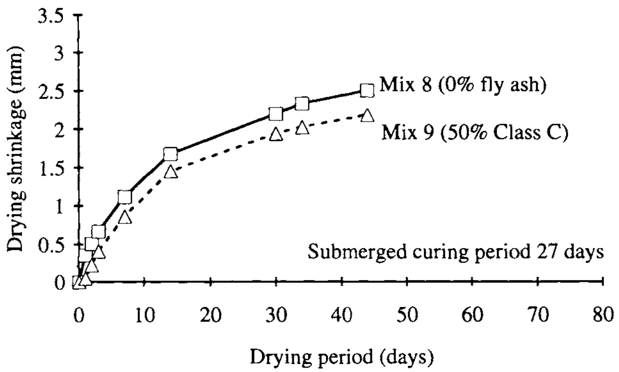

Fig. 15—Drying shrinkage of pastes with and without Class C fly ash (specimens with 27 days' submerged curing condition)

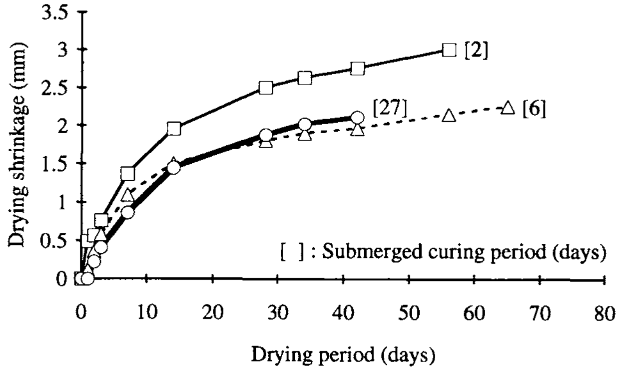

Fig. 16—Drying shrinkage of cement pastes with different submerged curing condition

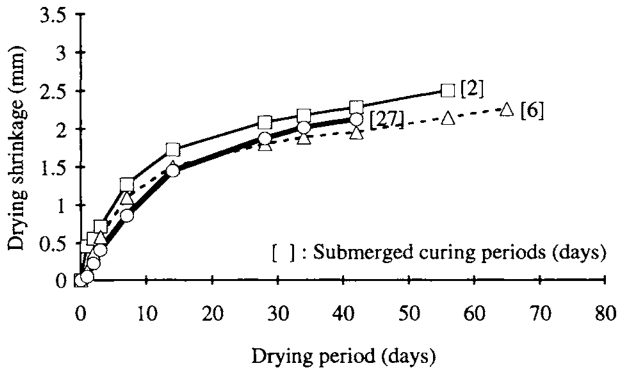

Fig. 17—Drying shrinkage of pastes with 50 percent Class C fly ash with different submerged curing condition

SP 153-23

Construction Experience with CLSM Fly Ash Slurry for Underground Facilities

by B. W. Ramme, T. R. Naik, and H. J. Kolbeck

Synopsis: This paper presents the results of research performed in developing and using flowable fly ash slurry which is classified as a Controlled Low Strength Material (CLSM) as defined by ACI Committee 229 for underground facility construction and abandonment.

The mixture proportions for the CLSM described in this paper used fly ash as a primary ingredient. The fly ash was produced at Wisconsin Electric's Port Washington Power Plant as a by-product of burning coal from Pennsylvania. Port Washington Power Plant has four 80 MW electric generating units that were brought in service between 1935 and 1949. Additional ingredients included portland cement, water and conventional fine and coarse aggregates.

Information is also included on the compressive strength, electrical resistivity, thermal conductivity and compatibility with plastics used in the manufacture of underground electric cable jackets and natural gas lines.

The results indicate that CLSM fly ash slurry is an excellent material for backfilling trenches and filling abandoned underground facilities.

Keywords: Backfilling; compaction; compressive strength; electrical resistance; flowability; fly ash; slurries; subsurface structures; thermal conductivity

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INTRODUCTION

The objective of this project was to expand the existing use of CLSM fly ash slurry being produced at Wisconsin Electric power plants. Projects using flowable fly ash slurry produced at the company's Valley Power Plant, located in downtown Milwaukee, date back to 1983. It was used at that time for the abandonment of underground steam tunnels, shafts, vaults and pipelines (1). Production of CLSM at Valley Power Plant was accomplished by loading the fly ash directly into ready-mix trucks from the wet unloaders located under the ash storage silos that are routinely used for loading open dump trucks. The ready mix trucks would arrive loaded with the required amount of portland cement and water; the desired amount of fly ash would be batched by timed filling and then the truck would proceed to a scale. Additional ash or water were then added to achieve the desired mixture proportions and flowability. This process involved some spillage of fly ash when loading the trucks and required close control by an operator.

Port Washington Power Plant is located in the City of Port Washington, Wisconsin, approximately 40 kilometers north of Milwaukee and is undergoing a major renovation to significantly extend the plants life. A new fly ash collection, handling and mixer unloading system is being added as part of this renovation. This presented an opportunity to incorporate a portland cement silo and batching equipment to simplify the CLSM production process. This equipment became operational in May of 1993. Trial batches were produced by the Valley Power Plant method to demonstrate the feasibility of using Port Washington Power Plant fly ash for the production of CLSM. Two construction projects were also supplied with CLSM material to further demonstrate it's practical capabilities. Initial CLSM fly ash slurry applications in Wisconsin were limited to the abandonment of underground facility voids such as tunnels, manholes, vaults, underground storage tanks, sewers and pipelines. Another obvious utility application is the backfilling of trenches for underground lines. In these applications, it is imperative that the material be excavatable, compatible with the underground line materials and provide the required thermal properties of a backfill for underground high voltage transmission lines. Results of these studies were positive and CLSM fly ash slurry has been used to backfill trenches for various steam and electric utility lines.

LITERATURE REVIEW

A comprehensive bibliography on the use of controlled low strength materials was recently published in Concrete International magazine (2) and therefore will not be repeated here. Two additional papers on medium to high strength CLSM fly ash slurry work at Wisconsin Electric Power Company using ASTM C 618, (Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete) Class C or F fly ash for sub-structural and backfill applications have also been reported.(3)(4) Three papers were also found on the thermal properties of backfill for underground cables.(5)(6)(7)

MATERIALS

Fly ash produced at Port Washington Power Plant, ASTM C 150, (Specification for Portland Cement) Type 1 cement and the local municipal drinking water supply were used in all mixtures. No admixtures were used. ASTM C 618 chemical test results are not available for the Port Washington fly ash because it is not normally used in concrete. The loss on ignition of the fly ash was 10.9%. Physical tests were performed and are shown in Table 1. ASTM C 618 test data is available for the Valley Power Plant fly ash which uses the same coal source as Port Washington Power Plant and is shown in Table 2. Concrete sand and 19 mm maximum size coarse aggregate were used in some trial mixtures. No admixtures were used.

EXPERIMENTAL

Mixture Proportions

A small laboratory scale mixture was made at the Center for By-Products Utilization at the University of Wisconsin-Milwaukee in November, 1991. Four trial batches were made with and without aggregates in a local ready mixed concrete supplier's mixers in July, 1992 in nominal five cubic yard batches. These mixtures and compressive strength results are shown on Tables 3 and 4 respectively.

Mixture #1 contains no aggregates and the largest quantity of fly ash. Mixture #2 contains sand while Mixture #3 contains 19 mm coarse aggregate. Mixture #4 with both sand and 19 mm coarse aggregates was proportioned to meet the Wisconsin Department of Natural Resources exemption for maximum permissible quantities of fly ash used in ready mixed concrete.

The electrical resistivity, thermal conductivity and plastics compatibility testing was performed on solid CLSM fly ash slurry material made from a mixture containing 578 kg. of Valley Power Plant fly ash, 68 kg. of Type 1 Portland Cement and 476 kg. of water per cubic yard.

Specimen Preparation and Testing

Standard 150 mm diameter by 300 mm long cylindrical specimens were prepared for tests of compressive strength. Typically, two cylinders were tested at ages of 1, 3, 7 and 28 day ages in accordance with ASTM test procedure C 39, (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens). Additional cylinders that had been buried below frost and some that had been stored dry in the laboratory, were tested at an age of two years. Results are shown in the bottom half of Table 4.

Electrical resistivity tests were performed in the laboratory on six samples prepared in accordance with California Test 643-1978, (Method for Estimating the Service Life of Steel Culverts). The moisture content of the samples varied from 20% to 100%. The results of these tests are shown on Table 5.

Thermal conductivity tests were conducted on six samples using the thermal needle test method(8). The moisture content of the samples ranged from 0 to 77 percent and the dry density varied from 800 to 900 kg/m^3. The results of these tests are shown on Table 6.

DISCUSSION OF RESULTS

The compressive strength results of mixtures 1 through 3 were very comparable and followed known patterns. The 0.27-0.43 MPa strength at 28 days is quite comparable to many undisturbed or re-compacted soils and makes it suitable as a backfill material. Although these materials will continue to gain some strength they should be easily excavatable with conventional equipment. The fourth mixture with mixture proportions similar to a conventional ready mixed concrete with low cement content produced a 28 day strength of 1.9 MPa. This mixture will also continue to gain strength and can be used in higher strength applications such as below foundations where future excavatability concerns are not important. Additional comparison strength tests were conducted at the age of two years. The two year strength results in both a buried (below frost) and dry (ambient temperature) environment did not show significant strength changes as shown in Table 4.

Electrical resistivity measurements are useful in predicting the corrosiveness of soils. The list below provides a rough indication of Soil Corrosivity vs. Resistivity.

Resistivity (ohm-cm)	Description
Below 500	Very corrosive
500- 1,000	Corrosive
1,000-2,000	Moderately corrosive
2,000-10,000	Mildly corrosive
Above 10,000	Progressively less corrosive

The electrical resistivity measurements on the CLSM fly ash slurry ranged from a high of approximately 214,000 ohm-cm at 20 percent moisture to a low of approximately 60,000 ohm-cm at moisture contents of 60% and higher as shown on Table 5. These values are all well above the values shown above; indicating the CLSM fly ash slurry is not considered to be corrosive.

The thermal conductivity results exhibited a near linear relationship with moisture content. Values ranged from a low of 0.08 (BTU/hr-ft-F) at 0% moisture to 0.53 at 63% moisture. As the moisture content and dry density increase, so does the CLSM's thermal conductivity. Thermal conductivity values of the fly ash slurry are typically lower than sands, silts and clays, and higher than peat. Where high thermal conductivity is desired, such as backfill for underground power cables, high density and very low porosity (maximum surface contact area between aggregate particles) are desirable.

A plastics compatibility study (9) was performed by Dr. Henry E. Haxo, Jr. of Matrecon, Inc. of Alameda, California for Wisconsin Electric Power Company. Samples of polyethylene pipe and polyethylene coated steel pipe used for natural gas lines were analyzed and found to have densities of 0.935 and 0.949 g/cm^3 which were medium and high densities respectively. A sample of electric power cable jacket was identified as linear low density polyethylene. The low permeability of the polyetheylenes that were used to manufacture these pipes and cable jackets would minimize the entrance of water and ionic species into the cable or pipe per Dr. Haxo. The basic conclusion of his report is that the polyethylene pipe and jacketed cable would not be adversely affected by the CLSM fly ash slurry. Dr. Haxo did express some concern regarding possible damage to the coated steel pipe during installation from aggregate. An inadequate coating, particularly at the joints, could expose the steel to liquids in the backfill. This is an application and installation issue which is present regardless of the type of backfill. It would seem the fine gradation of the fly ash slurry and it's flowable nature would aid in minimizing scratching and nicking the polyethylene surface.

CONSTRUCTION

Construction experience with Port Washington flowable fly ash CLSM has been limited to two projects during the 1992 construction season. The first project involved the abandonment of a 76.2 cm diameter natural gas main in St. Francis, Wisconsin associated with the Lake Arterial highway project. Approximately 57 cu.m. of material were successfully used on this abandonment project in August of 1992. The second project involved backfilling an underground electric cable trench adjacent to the fire department building in downtown Cedarburg, Wisconsin. Approximately 73 cu.m. of material were used on this project during November of 1992.

A few practical construction considerations must be remembered when using these CLSM materials. Flowable fly ash CLSM is a liquid when poured into an excavation. This material exerts a hydrostatic pressure that needs to be considered when placing it along basement walls or similar structures. Multiple lifts after setting and hardening has occurred may be required. The mixture ingredients and amount of water used will affect the time of set. Many CLSMs require 8-24 hours to harden. Trenches of liquid CLSM material must also be covered or otherwise protected to prevent accidental entry by the public. Another consideration when backfilling around pipes, conduits and power lines is that they may float while placing CLSM if not secured.

NEW EQUIPMENT

A new fly ash handling, storage and unloading system was installed at Port Washington Power Plant as part of a larger plant renovation project. The system consists of a vacuum transportation system that sends the fly ash collected by electrostatic precipitators to two 425 cu.m. storage silos. One silo has been equipped with an internal 20 cu.m. capacity cement silo and a batching system to accurately measure the quantity of cement, fly ash and water that is placed into a 4 cu.m. batch mixer. This system becameoperational in May 1993 and has significantly reduced the production cost of flowable fly ash CLSM by eliminating the double handling of it's main ingredient. The system also provides dust free, spill free and accurate batching of the component materials.

CONCLUSIONS

The following conclusions may be drawn from the executed tests:

- CLSM flowable fly ash slurry can be successfully produced for trench backfill and underground facility abandonment with Port Washington Power Plant's fly ash.

- The addition of a cement silo and batching system to a plant fly ash unloading system simplifies the mixing of CLSM flowable fly ash slurry and eliminates double handling of the mixtures main ingredient, fly ash.

- The corrosion potential of CLSM flowable fly ash slurry produced with fly ash derived from the combustion of the Pennsylvania coal used at Port Washington Power Plant is significantly less than that of typical soils used for trench backfill.

- CLSM fly ash slurry is not expected to adversely affect polyethylene natural gas lines or polyethylene jacketed power cables due to its high impermeability. Care must be exercised when backfilling polyethylene coated steel natural gas pipelines with all backfill materials to prohibit scratching or damage to the coating.

- High density very low porosity CLSM should be used where high thermal conductivity is desired such as backfill around underground power cables.

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