SP 150-1

Low-Strength Concrete and Controlled Low-Strength Material (CLSM) Produced with Class F Fly Ash

by T.R. Naik and B.W. Ramme

Synopsis: This paper presents results of research performed to identify optimum mix proportions for production of Controlled Low Strength Material (CLSM) with high fly ash content. CLSM is defined by the ACI Committee 229 as a cementitious material that is in a flowable state at the time of placement and having a specified compressive strength of 1,200 psi (8.3 MPa or 172,800 lbs./sq. ft.) or less at the age of 28 days. The fly ash used in this study met the requirements of ASTM C 618 for Class F material. Tests were carried out on concrete designed to have 500 - 1,500 psi compressive strength at the 28-day age with fly ash contents of approximately 500 lb/yd^3. Slump was held at 8$\pm$ 1 inch for all mixtures produced. Compressive strengths at 28 days were found to range from 290 to 1,640 psi. Construction experience and other planned applications are also discussed.

Keywords: Backfilling; compressive strength; controlled low-strength material (CLSM); density (mass/volume); flowability; flowable fill; fly ash; low strength concrete; mix proportioning; slump; slurries; tests

ACI Fellow **Tarun R. Naik** is director of the Center for By-Products Utilization and an associate professor of civil engineering at the University of Wisconsin, Milwaukee. He receive his BE degree form the Gujarat University, India, and MS and PhD degrees from the University of Wisconsin, Madison. He is a member of ACI Committees 201, Durability of Concrete; 231, Fly Ash and Natural Pozzolans in Concrete; 123, Research; Concrete Materials Research Council; E 801, Student Concrete Projects; and 214, Evaluation of Results of Tests Used to Determine Strength of Concrete, and others.

ACI member **Bruce W. Ramme** is Assistant to the Plant Manager at the Port Washington Power Plant of Wisconsin Electric Power Company, Milwaukee, He received his BS and MS degrees in structural engineering from the University of Wisconsin, Milwaukee. He is a member of ACI Committees 229, Controlled Low Strength Material; and 213, Lightweight Aggregates and Lightweight Aggregate Concrete.

INTRODUCTION

This paper presents the results of research performed to identify mix proportions for low strength concrete slurry which falls under the classification of Controlled Low Strength Material (CLSM) as defined by ACI Committee 229. CLSM is defined as a cementitious material that is in a flowable state at the time of placement and has a specified compressive strength of 1200 psi (8.3 MPa or 172,800 lbs./sq. ft.) or less at the age of 28 days. It is primarily used for nonstructural applications below grade where low strength is required. In some cases it is intended to be no stronger than the surrounding soil. The CLSM described in this paper has a 28 day compressive strength of 500 psi (3.4 MPa) and higher with some mixtures actually producing strengths in excess of 1200 psi (8.3 MPa) which fall into the category of low strength concrete. Low strength, 100 psi ± 50 psi (0.7 MPa ± 0.35 MPa) CLSM flowable fly ash slurry produced as part of this overall project has already been described in a previous publication [1]. The type of CLSM selected should be based on technical and economic considerations for the specific application. The fly ash used in the CLSM for this project was produced by Wisconsin Electric Power Company (WE) at the Valley Power Plant located in Downtown Milwaukee, Wisconsin. The plant uses bituminous coal from Pennsylvania Mining District 2.

The mix proportions for the CLSM used in this project were selected to obtain a moderate strength material in the 500 psi (3.4 MPa) to 1500 psi (10.3 MPa) (72 to 216 kips/sq. ft.) range. This level of strength is similar to that of many naturally occurring bedrock formations and, therefore, provides excellent support for foundations and can assist in distributing foundation loads over greater areas.

The scope of the research phase reported in this paper is limited to developing mix proportions consistent with specified strength and flowability requirements.

Literature Search

A library search was conducted to identify existing similar work with respect to the development of high fly ash low strength concrete. Published reports by federal and state organizations, engineering periodicals and journals, and professional organizations were reviewed.

The primary search covered the period from January, 1970 to June, 1988. The only similar work found on low strength fly ash concrete was done by the Detroit Edison Company, Detroit, Michigan, and the Kuhlman Corp., Toledo, Ohio in 1970[2]. The investigation done by these companies resulted in the development of a new product that was called K-Krete. As a result of this development, a K-Krete Corporation was formally organized in 1974. The K-Krete mix consists of Portland cement, fly ash and a filler. The primary use of K-Krete is as a replacement for compacted granular materials. Such uses include street utility backfills, sanitary backfills, backfills around foundations, etc. The compressive strength for K-Krete mixes ranges between 100 - 1600 psi (0.7 MPa - 11.0 MPa). The permeability ranges between 0.001 to 0.00003 ft/min (0.3 to 0.009 mm/min), which indicate that the K-Krete mixes have comparable permeabilities when compared to regular backfill materials (e.g., silty sand permeability varies from 0.002 to 0.00002 ft/min (0.6 to 0.006 mm/min). The K-Krete materials had resistance to direct wearing erosion similar to that for a comparable granular fill. It was suggested that for removability K-Krete mixes should be designed for about 100 psi (0.7 MPa) compressive strength at one year age. It was recommended that research is needed to investigate and develop the fly ash low strength concrete to meet user needs.

The July 1990 issue of Concrete International featured articles on CLSM. An article written by Ron Larsen [3] sites several excellent application examples on uses of this material including filling of abandoned underground fuel tanks, protecting under-road petroleum pipes, placing culverts, erosion prevention, saving bridges and steel arch pipe culverts and filling voids.

Several fly ash concrete and slurry publications [4-21] are identified in the bibliography to give the reader leads to other work with similar fly ashes and their applications.

OBJECTIVES AND SCOPE

The mix proportions for the low strength concrete in this project were selected to obtain a low strength material in the 500 to 1500 psi (3.4 to 8.3 MPa) range. This level of strength makes it suitable as a low cost material for pipe bedding, utility duct envelopes, for filling over-excavated zones under structural foundations, as a high quality road base, and in similar applications. This material can serve as a non-structural material at a cost lower than normal structural concrete in applications where lower strengths are adequate. The material should not be used for above grade applications without being properly protected, i.e., covered, since it does not possess qualities that make it durable against freeze-thaw and abrasion exposure.

Valley Plant Class F Fly Ash

Valley Plant Class F fly ash is a by-product of Eastern United States bituminous coal combustion. The fly ash is captured by electrostatic/precipitators from flue gases prior to discharge by exhaust chimneys. It meets the requirements of ASTM C618 Class F Designation, see Table 1.

Materials and Mixing

The high fly ash low strength concrete mixes were produced for this project at a batch plant of the New Berlin Redi-Mix Concrete Co., New Berlin, Wisconsin. The fly ash was stored in separate silos in a dry state. The cement used in these tests was Type I. The mixing water was heated. The fine aggregates used were a natural sand material meeting ASTM Test Designation C-33 with a fineness modulus of 2.79. The maximum size of coarse aggregate was 3/8 in. (9.5 mm) (pea gravel). No air entraining agent was used. The materials were loaded into a ready mix truck and transported form the batching plant to an on-site location where the tests were performed. The batch quantity for each mix was approximately two cubic yards (1.5 cubic meters). The concrete batch in the truck was allowed to mix at the transit speed of the mixer drum for about 30 minutes. A small front end loader was used to obtain the desired quantity of concrete, about 4 cu. ft. (0.11 cu.m.) to perform the tests and make the test cylinders for each mix. Each time about two front end loaders full of concrete, about 8 cu. ft. (0.23 cu.m.) were discarded before taking the final sample for testing and cylinder casting to assure homogeneity of the product.

Preliminary Mix Proportioning

Preliminary mix proportions were developed to produce CLSM with a low cement factor but a high proportion of fly ash and sufficient water to produce high workability and/or fluidity. The slump was targeted for the 5 to 8 in. (127 to 203 mm.) range for the special construction applications described in the scope.

Final Mix Proportioning

Mixes F-1 to F-6 were produced with a low cement content and a high fly ash to cement ratio to compensate for the low cementitious characteristics of the Class F fly ash. These mixes were all high in slump, 7 in. - 9 in. (180 mm - 230 mm) range. Adjustments which were made in the sand and pea gravel content versus the total cementitious (cement plus fly ash) material. Generally, the sand content was decreased as the total cementitious material, in particular the fly ash content, was increased. These adjustments were necessary in order to produce the required volume of concrete as the fly ash amount was increased in order to maintain the batch yield. These adjustments have no significant influence on the concrete properties.

All Mixes were produced in 2 cu. yd. (1.5 cu.m.) batches. The total batch weights were recorded for each mix. The final mix proportions per cubic yard were calculated for all mixes using the actual material weights and unit weights of each batch. (Table 2).

Specimen Preparation and Testing

Each batch of concrete produced was tested for acceptability before proceeding with the other tests. Tests for slump, concrete and ambient air temperatures, air content and unit weight were performed for each batch. Observations were made to determine the workability of the concrete. All batches of concrete were homogeneous and cohesive.

From each concrete mixture, 6 in. diameter by 12 in. high (150 mm x 300 mm) cylinders were prepared for compressive strength and other tests. Three cylinders were tested from each mix at nominal ages of 3, 5, 7 and 28 days. Cylinders were stored at room temperature, 65 ± 5°F, for three days before being transported to the testing laboratory for storage in a moist room and strength testing at specified ages.

All mixes showed good flowability and workability. Shrinkage ranged from 0 to 1/32 in. (0 to 1 mm). The cylinders were stripped without problems when they were brought to the laboratory and their sidewalls appeared smooth.

DISCUSSION OF RESULTS

The compressive strength test results are shown on Table 3 and Figure 1. Twenty eight day strengths ranged from 500 psi (3.4 MPa) to 1600 psi (11 MPa). The ratio of fly ash to cement ranged from 5.5 to 2.2. The ratio of water to total cementitious material was approximately 0.60 by weight.

Mixes F-1 to F-6 show that a high slump, low cement, and high amount of Class F fly ash concrete can be produced that can attain strengths in the 1600 psi range. The data indicates that the presence of a large proportion of non-cementitious material present in Class F fly ash limits the strength gain that can be attained for this type of mix. Figures 2 and 3 show that this limit is in the order of 1600 psi. An increase in the cement to fly ash ratio might produce somewhat higher compressive strengths by providing more available cement for the pozzolan used.

Field observations also confirmed that these mixes showed good flowability and good workability, however, they did not lend themselves to a high grade of trowel finishing which isn't really required for the intended applications.

Figure 4 shows the influence of varying the cement content on the 28-day compressive strength. For similar workability, the cement content was an important factor for the Class F fly ash concrete, mixes F-1 to F-6. As the cement content was increased the 28-day strength also increased proportionately.

WE Project Experience with Low Strength Concrete

Low strength concrete with Class F fly ash was used in 1977 for backfilling a steam main extension trenchbox excavation. The mix proportions were:

Cement	50 lbs.
Fly Ash	600 lbs.
Sand	2900 lbs.
Water	320 lbs.

The compressive strength produced was in the range of 400 psi, at 28 days and set hard enough to walk on in 8-10 hours. Since the material flowed very easily it was possible to do the backfilling with the steel plates in place over a street crossing, thus keeping the street open for use throughout the backfilling operation.

The majority of WE's experience with low strength concrete in recent years involves the use of Class C fly ash and is described in another paper [21]. This is largely because local ready mix suppliers maintain an ample supply of the material for structural concrete applications and do not have additional storage silos. However, this Class F fly ash has been used for some large volume projects in the form of a flowable fly ash slurry CLSM material [1].

As supplies of the highly desired Class C fly ash diminish because of demand and local ready mixed concrete suppliers begin to offer the flowable fly ash slurry for smaller jobs (which means they will have a silo or another method of storing Class F fly ash), WE expects to also use more of the low strength concrete produced with Class F ash.

CONCLUSIONS

1) Generally, as the water to cementitious material ratio increased, the compressive strength decreased. The cement content was very important in these mixes as the fly ash used possessed very little cementitious property of its own.

2) All mixes showed good flowability and workability. Shrinkage was minimal or non existent.

3) All mixes performed well and can be used as the basis for selecting mix proportions for CLSMs or low strength high fly ash concrete with high slump for non-structural applications using the same materials.

4) High fly ash content low strength concrete and CLSMs can be made with Class F fly ash and can be successfully used in construction.

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TABLE 1 — CHEMICAL AND PHYSICAL TEST DATA FOR CLASS F FLY ASH FROM VALLEY POWER PLANT

Chemical Composition	Number of Samples	Range, Percent	Average Percent	ASTM C-618
Silicon Oxide, SiO_2	4	50.06-50.20	50.14	---
Aluminum Oxide, Al_2O_3	4	25.24-25.36	25.27	---
Iron Oxide, Fe_2O_3	4	14.66-15.39	14.93	---
Total, SiO_2+$A1_2O_3$+Fe_2O_3	4	89.96-90.82	90.36	70 Min.
Sulfur Trioxide, SO_3	4	0.20-0.33	0.26	5.0 Max.
Calcium Oxide, C_aO	4	1.18-1.44	1.27	---
Magnesium Oxide, M_gO	4	0.70-0.74	0.71	5.0 Max.
Loss on Ignition	4	3.59-6.94	5.08	6.0 Max.
Available Alkalis as Na_2O	4	1.61-1.70	1.65	
Sulfur			0.22	
Physical Tests				
Fineness, % Retained on #325 Wet Sieve	1	25	25	34.0 Max.

Note: 145 psi = 1 MPa
1 inch = 25.4 mm
$1^oF=1.8^oC + 32$
1 cu. yd. = 0.7646 cu.m.
1 pound = 0.4536 kg

TABLE 2 — MIXTURE PROPORTIONS AND FIELD TEST DATA FOR HIGH FLY ASH LOW STRENGTH HIGH SLUMP CONCRETE USING CLASS F FLY ASH
(Supplier: New Berlin Redi-Mix, Inc.)

Mix No.	F-1	F-2	F-3	F-4	F-5	F-6
Specified Strength at 28-day age, psi	500	1000	1500	500	1000	1500
Cement, lb./cu. yd.	102	151	229	138	211	263
Fly Ash, lb./cu. yd.	499	519	500	452	459	446
Water, lb./cu. yd.	439	375	422	323	294	320
SSD Sand, lb./cu. yd.	1206	1198	1111	1090	1053	1060
SSD Pea Gravel, lb./cu. yd.	1614	1697	1680	1783	1774	1688
Slump, in.	9	7-3/4	8-1/4	9	7-1/4	8-1/4
Air Content, percent	1.0	1.8	1.9	0.5	1.4	1.7
Air Temperature, °F	38	36	35	32	33	33
Concrete Temperature, °F	65	64	64	58	60	62
Concrete Density, pcf	143.0	145.9	146.0	140.2	140.4	139.5
Concrete Weight, lb./cu. yd.	3861	3940	3942	3786	3791	3777
W/C W/C+FA*	4.3 0.73*	2.5 0.56*	1.8 0.58*	2.34 0.55*	1.39 0.44*	1.22 0.45*
Date Cylinders Cast	11/22/88	11/22/88	11/22/88	02/13/89	02/13/89	02/13/89

* May not be meaningful because all of the Type F fly ash probably should not be accepted as cementitious.

Note: 145 psi = 1 MPa
1 inch = 25.4 mm
1°F = 1.8°C + 32
1 cu. yd. = 0.7646 cu.m.
1 pound = 0.4536 kg