High Early Strength Concrete Containing Large Quantities of Fly Ash

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Abstract

This paper presents results of research performed at a precast/prestressed concrete plant to identify optimum mix proportions for production of high early strength concrete with high fly ash contents. Compressive strength, workability and water demand results are presented.

Introduction

The purpose of this project was to develop mix proportioning information for production of high early strength concrete with high fly ash content for precast/prestressed concrete products. The fly ash used in this project was produced by Wisconsin Electric Power Company (WE), at the Pleasant Prairie Power Plant located in Kenosha County, Wisconsin.

Test data from mix proportioning reported in earlier publications (10, 11, 12, 13, 14) clearly established that fly ash can be used for structural grade concrete in quantities of up to 60 percent replacement of cement. Demonstration projects are also reported in these publications which show that pavement construction and other projects have successfully used structural grade concrete with up to 70 percent cement replacement.

The objective of this paper is to report that high early strength concrete can be produced with high replacement of cement by fly ash for precast/prestressed operations. Effects of fly ash content on water demand and workability are also reported.

Tests were carried out on high-strength concrete, where fly ash was substituted for cement at levels up to 30 percent replacement of the cement. A literature search was also conducted to further study the water demand, workability, and

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strength characteristics for fly ash concrete. Rather than compiling an exhaustive annotated bibliography of the available literature, some important publications were reviewed in detail. They are listed in the references (1-24).

Pleasant Prairie Class C Fly Ash

The Pleasant Prairie Power Plant Class C Fly Ash is a by-product of Western United States sub-bituminous coal combustion. The fly ash is captured by electrostatic precipitators from flue gas prior to discharge by exhaust chimneys, and meets the requirements of the ASTM C618 Class C Designation, see Table 1. Until about fifteen years ago, most of the fly ash available from coal burning power plants in the U.S. was of the Class F (low calcium) variety. However, the introduction of low sulphur western sub-bitumous coal in the 1970's made Class C (high calcium) fly ash more readily available.

Class C fly ash has higher lime content than Class F fly ash and possesses some cementitious properties of its own. Therefore, the Class C fly ash can be used in higher proportions than the 15 to 20 percent range typically used for the Class F fly ash for structural quality concrete.

Mix Proportioninig

Mix proportions were developed for producing concrete on a 1.25 to 1.00 fly ash to cement weight substitution in the amount of 0, 10, 15, 20, 25 and 30 percent. Six different mix proportions of 8000 psi nominal compressive strength concrete were developed. Mix proportions and test data for the twelve mixes are given in Table 2.

Concrete Mixing

Concrete was produced at a precast/prestressed concrete plant in 2 cu.yd.test batches. Based on the preliminary mix proportions developed, the final mix proportions were completed in consultation with the concrete producer. All mixed were made with Type I Cement. Standard batching and mixing procedures for ready-mix concrete were followed, in accordance with the ASTM Test Designation C-94.

Specimen Preparation and Tests

Each batch of concrete produced was tested for acceptability before concrete tests were undertaken. Fresh concrete tests were performed and mix proportions were recorded (see Table 2). Tests for slump and air content were also performed and data recorded, (Table 2). Attention was also paid to maintaining constant workability for the concrete. From each concrete mix, necessary specimens were prepared for compressive strength tests.

Test Results and Discussion

Compressive Strength:

The compressive strength results are shown in Table 3. Figure I shows the compressive strength vs. age comparison for the 8000 psi mixes produced at the prestressed concrete plant.

Mix I is for the no fly ash concrete. Mixes 2 through 6 are compared to Mix No. 1, (i.e., fly ash concrete mixes were compared to the non-fly ash concrete Mix). Mix No. 2, which has 10 percent fly ash replacement, had a strength gain of 8%, 14%, 17%, and 11% for the 19-hrs., 22-hrs., 3-day, and 7-day ages, respectively, when compared to the non-fly ash concrete (Mix No. 1) , see Table 3. The strength gain was about 12 % for the later ages (14 days and 28 days). When the amount of fly ash replacement was increased the strength gain at early age was more pronounced. For example, Mix No. 4, which has 20 percent fly ash replacement, had a strength gain of 53%, 48%, 51% and 50% for the 19-hrs, 22-hrs, 3-day, and 7-day ages, respectively, when compared to Mix No. I, which had no fly ash (Table 3). Mix No. 6, which has the highest fly ash replacement, 30 percent, had even a higher strength gain at the 7-day age, 65 percent. These results clearly indicate that Class C fly ash usage increases the early age strength of concrete. Therefore, this Class C fly ash can be used to produce high early strength concrete, in quantities of up to at least 30 percent cement replacement as demonstrated by the data obtained for this project. Therefore, fly ash can be used to produce high early strength concrete for precast/prestressed applications.
Figure I provides a more complete picture of the strength improvement for fly ash concrete mixes when compared to no fly ash mixes.

Figure 2 shows similar strength goals for a different producer.

Water Demand

Figure 3 shows the relation between the percentage of fly ash replacement and the amount of water required for the same workability for the 8,000 psi nominal strength concrete. It is apparent from this figure that as the amount of fly ash content increases the water "demand" decreases, while maintaining approximately the same workability. For example, Mix No. I had zero percent fly ash replacement and the amount of water needed was 298 lbs., while Mix No. 6 had 30% fly ash replacement and the amount of water needed was only 229 lbs. for the same workability. Figure 4 shows similar test results for a different concrete producer.

Figure 5 shows the relation between the water to cementitious material ratio, by weight, and the percentage of fly ash replacement for this source of concrete (Table 2). It is also obvious from this plot that as the amount of fly ash replacement increases the water to cementitious material ratio decreases for the same workability. This is indeed a well documented fact in the literature. The data from this project confirms that fly ash concrete requires less water for the same workability as a similar concrete without fly ash.

Workability

Workability was observed and noted throughout the project. All of the concrete produced was homogeneous and cohesive irrespective of the amount of fly ash replacement. Slump readings noted in Table 2 shows no significant difference between the different mixes. Other researchers have reported that fly ash concrete improves workability and the data drawn from this project confirm this fact because even though the water to cementitious ratio decreased as the fly, ash content was increased, excellent workability was maintained.

Summary and Conclusions

The conclusions, which can be drawn from this project for the use of Type C fly ash, are:

(1) The test data clearly establishes that cement replacement of up to 30 percent with fly ash increases early age strength compared to the concrete made with no fly ash. Therefore, concrete mixes with the Type C ash can be used with confidence to produce high early strength concrete for precast/prestressed products.

(2) As the amount of fly ash used in a mix increases, the water required for the same workability in that mix decreases.

(3) Fly ash use improves the workability of the mix and thus allows a decrease in the amount of water used.

(4) For the same workability, the water to cementitious ratio decreased significantly as the fly ash content increases from zero to 30 percent replacement of cement.

Recommendations

Precast/prestressed product suppliers not using Class C fly ash should consider the advantages of using this material in their daily production. The apparent advantages are:

(1) Improved Economics - Improved economics are possible as a result of reduced raw material costs resulting in more competitive products over a wider geographical region.

(2) Higher Quality - Fly ash usage in concrete provides higher quality products including, higher density with reduced permeability, increased strength and other properties.

(3) Increased Productivity - Fly ash concrete mixes are handled more easily because of improved workability. Faster release of prestressing tendons is also possible because of increased early age strength with use of fly ash.

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Table 1: Chemical and Physical properties Test Data PLEASANT PRAIRIE POWER PLANT Class C FLY ASH

CHEMICAL COMPOSITION	NUMBER OF SAMPLES	RANGE (%)	AVE.(%)	ASTM C-618
Silcon Oxide (SiO_2)	9	32.90 - 35.60	34.39	-
Aluminum Oxide (Al_2O_3)	9	17.10 - 18.20	17.74	-
Iron Oxide (Fe_2O_3)	9	15.10 - 6.30	5.93	-
Total (SiO_2+Al_2O_3)	9	55.70 - 59.30	58.07	50.0 Min.
Sulfur Trioxide (SO_3)	9	2.68 - 3.42	3.08	5.0 Max.
Calcium Oxide (CaO)	9	26.40 - 29.60	27.52	-
Moisture Content	9	0.04 - 0.44	0.12	3.0 Max.
Loss On Ignition	9	0.20 - 0.63	0.39	6.0 Max.
Magnesium Oxide (MgO)	7	4.10 - 4.80	4.56	5.0 Max.
Available Alkalies as (Na_2O)	7	0.87 - 1.55	1.18	1.5 Max.

PHYSICAL TEST	NUMBER OF SAMPLES	RANGE	AVE.	ASTM C-618
Fineness, % Retained on #325 wet sieve	9	11.08 - 13.34	18.83	34.0 Max.
Pozzolanic Activity Index with cement, 28 days, %	9	91 - 133	111	75.0 Min.
with lime, 7 days, psi	9	910 - 1466	1029	800 Min.
Water requirement, % of the control	9	88 - 92	89	105 Max.
Soundness, Autoclave Expansion (%)	9	0.07 - 0.21	0.13	0.8 Max.
Specific Gravity	9	2.55 - 2.71	2.66	-

Table 2: CONCRETE MIX PROPORTIONS AND TEST DATA – 8000 PSI SPECIFIED STRENGTH

CONCRETE SUPPLIER: Prestressed Concrete Plan No. 1

MIX NO.	1	2	3	4	5	6
Specified Design Strength, psi	8,000	8,000	8,000	8,000	8,000	8,000
Cement, lbs	560	594	561	528	495	462
Fly Ash, lbs	0	80	120	160	200	240
Water, lbs *	298	273	256	248	239	229
Sand, SSD, lbs	1344	1344	1344	1344	1344	1379
1" aggregates SSD, lbs	1900	1900	1900	1900	1900	1900
W/(C+FA)	0.45	0.41	0.38	0.36	0.34	0.33
Slump, inches	2-3/4 **	6-1/2	6-3/4	4-3/4	7	4-1/4
Air Content, %	5.4	4.5	2.4	2.0	2.1	1.6
Air Temperature, °F	70	70	70	70	70	70
Concrete Temperature, °F	69	66	70	69	69	69
Concrete Density, pcf	148.0	149.5	153.0	154.7	153.4	154.9

* 90 liq. oz. WRDA-19 (superplasticizer) added to all mixes

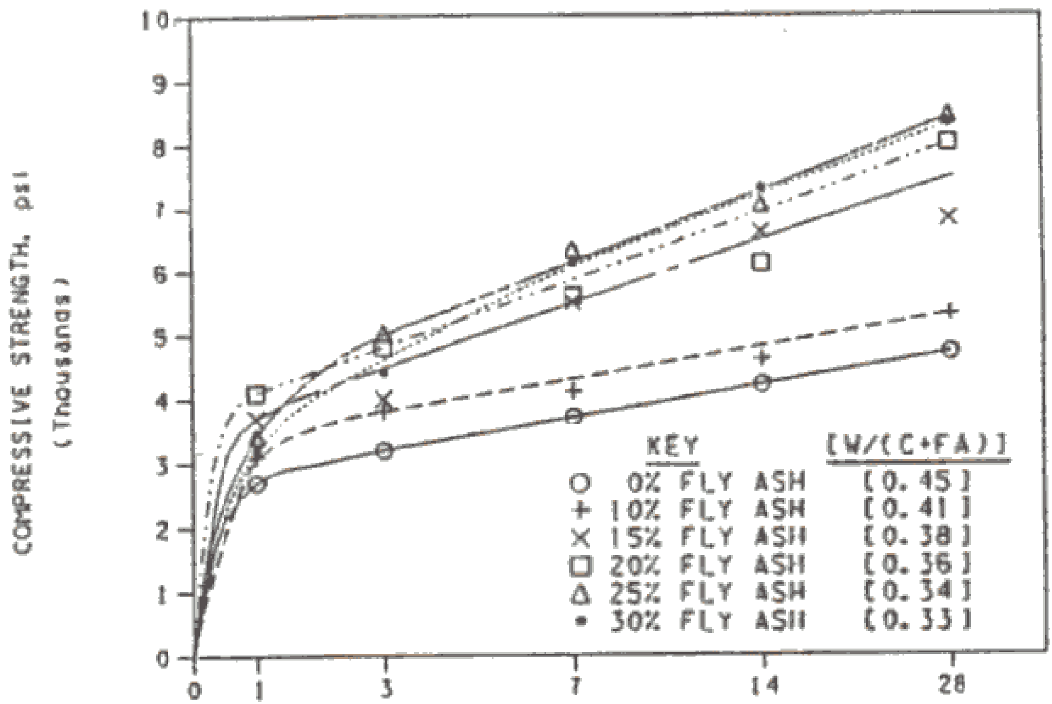
** Reduced slump because of delay in testing – actual slump approximately 5″ initially when the truck arrived

Table 3: CONCRETE STRENGTH TEST DATA – 8000 psi SPECIFIED STRENGTH, PLANT NO. 1

MIX NO.	1	2	3	4	5	6
Specified Strength, psi	8000	8000	8000	8000	8000	8000
Percent Fly Ash	0	10	15	20	25	30

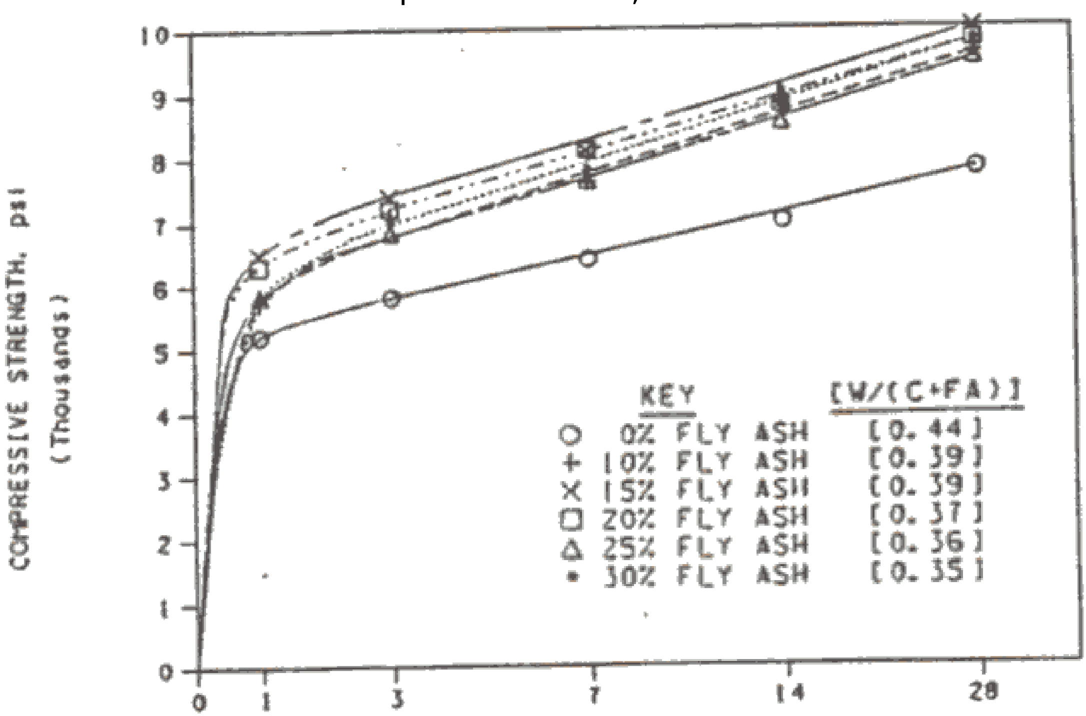
Test Age, Days	COMPRESSIVE STRENGTH, psi											
	Act.	Ave.	Act.	Ave.	Act.	Ave.	Act.	Ave.	Act.	Ave.	Act.	Ave.
19 hrs	2720		2950		3330		4170		3860		3110	
22 hrs	2790		3180		3750		4140		3400		3290	
3	3040	3235	3710	3800	4100	4095	4900	4890	4990	5060	4280	4475
3	3430		3890		4090		4880		5130		4670	
7	3860	3750	4210	4155	5590	5520	5160	5640	6510	6315	6260	6170
7	3640		4100		5450		6120		6120		6080	
14	4070	4210	4740	4685	6650	6615	5910	6175	7110	7075	7110	7305
14	4350		4630		6580		6440		7040		7500	
28	4740	4774	5270	5395	7360	6830	8450	8080	8770	8435	8520	8365
28	4810		5520		6300		7710		8100		8210	

Figure 1: COMPRESSIVE STRENGTH VS. AGE COMPARISON
5000 psi concrete, Plant No. 1



Age (days)

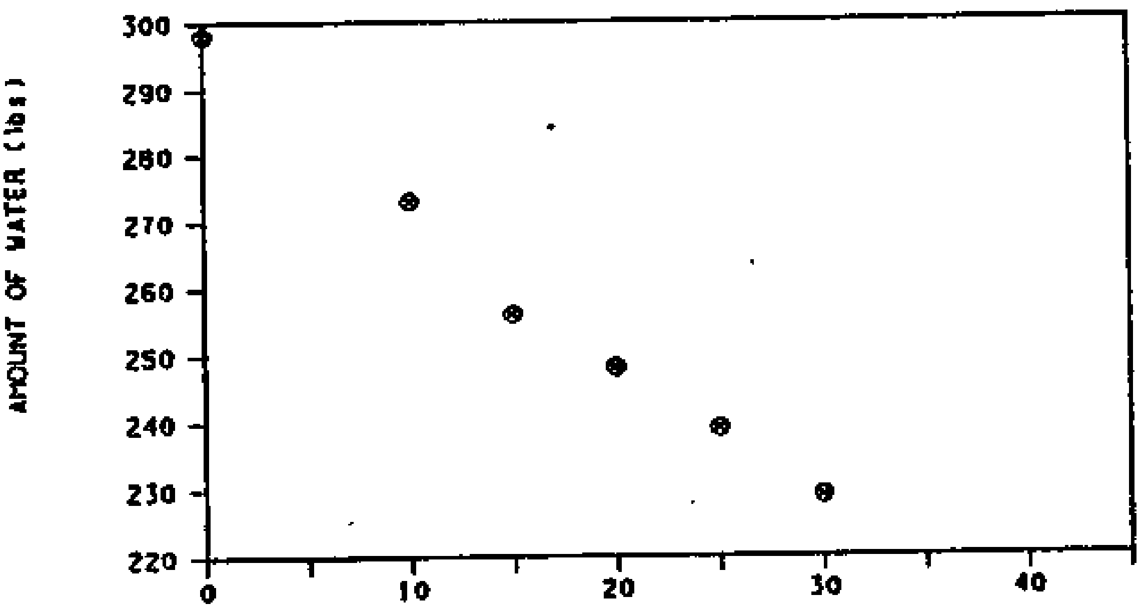
Figure 2: COMPRESSIVE STRENGTH VS. AGE COMPARISON
5000 psi concrete, Plan No. 2



Age (days)

Figure 3: RELATIONAHIP BETWEEN PERCENT CEMENT REPLACEMENT BY FLY ASH AND WATER DEMAND

Plant No. 1



Percent Cement Replacement by Fly Ash

Figure 4: RELATIONAHIP BETWEEN PERCENT CEMENT REPLACEMENT BY FLY ASH AND WATER DEMAND

Plant No. 2

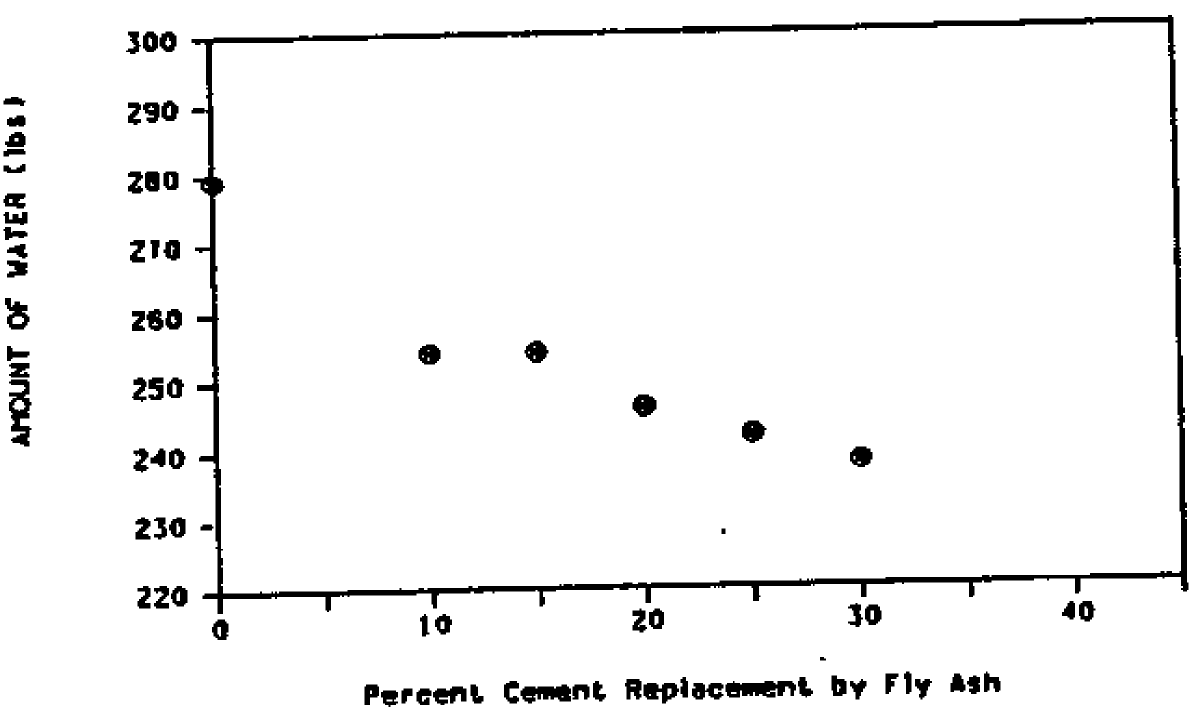


Figure 5: RELATIONAHIP BETWEEN PERCENT CEMENT REPLACMENT BY FLY ASH AND WATER TO CEMENTITIOUS RATIO
For Plant No. 1 and Plant No. 2