FINAL REPORT

ON

CORROSION OF REINFORCING STEEL IN CONCRETE CONTAINING FLY ASH

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INTRODUCTION

In July 1979, the Oklahoma Department of Transportation funded a research program at Oklahoma State University concerned with the performance of concrete containing fly ash (State Study No. 79-11-3). Initially, attention was directed towards the influence of fly ash on the corrosion of reinforcing steel. A study of available literature did not indicate that past use of fly ash had been detrimental from a corrosion standpoint. During a meeting with the Research Advisory Committee in early 1980, it was concluded that an experimental study of the influence of fly ash on corrosion was not warranted at this time and attention should be given to other factors related to the use of fly ash in concrete. A brief summary of the literature study was submitted to the sponsor in April 1980.

In May 1980, a work program covering the remaining months of the project was approved. This effort, which was to develop general data concerned with the strength of mixes containing various percentages of fly ash, is the subject of this report.

During this phase of the project, type I portland cement was replaced by fly ash on a weight basis. The percent replacement varied from 0 to 50 in. increments of 10 percent. Both coarse and fine aggregates used conformed to ASTM Standard C33 (see Appendix A), while the air entraining conformed to the Highway Specification, Section 701 (1).

EXPERIMENTAL DETAILS

Using trial batches, the proportions of cement, fine aggregate, and coarse aggregate that would produce a Class A concrete were determined. In these trial batches water and air entraining agent were added in different amounts and blended with the other materials until the fresh concrete properties of a class A concrete were realized, i.e., percentage of air entrained and slump. After the proportions were established, three batches of similar proportions were prepared within a 12-hour period for each percentage of fly ash. All batches were prepared from materials from the same source and mixed with the same mixer.

PREPARATION OF TEST SPECIMENS

The three batches were used to prepare specimens from which time of set reading were obtained as well as specimens that were tested at 7, 14, 28, and 90 days for compressive, flexural, and splitting tensile strengths and compressive modulus.

The first batch mixed for each percentage change of fly ash had a volume of 2 cu ft and was used to butter the mixer. A mortar sieved from this concrete was also used to cast a time of set specimen. Each of the other two batches was 4.5 cu ft in volume.

All specimens were prepared and cured with respect to ASTM C192 (2). For compressive strength and modulus, and splitting tensile strength, 6 by 12 in. cylinders were used. For flexural strength, beams were either 6 by 6 by 24 in. or 6 by 6 by 36 in. All specimens were cast in steel molds, which were waxed to prevent leakage, and cured in a moist room. Each test was performed with respect to its specific ASTM standard.

EXPERIMENTAL RESULTS

In Table 1, results associated with the characteristics of the fresh concrete and mix proportions are presented.

There is a constant ratio of the weight of total cementitious material to weight of coarse and fine aggregate. The amount of air entraining agent increased with an increase of fly ash while the water-cement ratio tended to decrease. The temperature of the mixes ranged from approximately 79 to 83°F. Air content and slump were within the respective allowable ranges of a Class A concrete.

The times of initial and final set demonstrated a strong correlation with percent fly ash replacement. The time of set appears to increase linearly with percent fly ash.

Powers Remolding Test (3) was performed in an effort to distinguish between the slump and the workability of the fresh concrete. Data from this test did not indicate that fly ash will increase the workability of the mix.

Table 2 presents the results of tests on hardened concrete at various ages. The strengths of concretes containing fly ash are lower than those of concrete without fly ash at an early age. However, after additional curing time the strengths were not as strongly related to the fly ash content.

DISCUSSION OF RESULTS

Time and cost restraints have not permitted all aspects of mix design to be investigated. To permit comparison with other available data, replacement of cement on a weight basis only was considered. Because of a slight difference in the specific gravity of portland cement and fly ash, some minor variation in total pounds of cementitious material (cement plus fly ash) per volume of concrete resulted. This approach allowed the amount of water and air entraining agent to be studied.

Probably the most notable observation to date is the strength characteristics of concretes containing fly ash. There appeared to be only minor differences in compressive strength between normal concrete and fly ash concrete if the percent replacement did not exceed 30 percent. Even concretes with 40 or 50 percent fly ash were nearly as strong as the control mixes after prolonged curing. This finding is in substantial agreement with data from laboratory work sponsored by a fly ash marketing firm in Oklahoma.

However, some results do not coincide with existing data. In particular, the amount of air entraining agent needed to achieve a suitable air content increased with the amount of fly ash. Although this is the anticipated finding based on published research, it is contrary to results obtained by Consulting and Research Services, Inc. (4).

Some difficulties were encountered in developing the desired proportions of a trial batch of approximately 2.0 ft^3 and then increasing the batch size to approximately 4.5 ft^3 when fly ash was used. These problems may not be related to the fly ash itself, but to the larger number of batches cast with fly ash compared to controls, or to other undetected variations in mix parameters.

Class A concrete is specified to have a slump range of 1 to 3 in. and an air content between 5 and 7 percent. Data were usually obtained from batches with a slump near the 3 in. limit. A subjective observation was that a slump near the lower limit resulted in erratic air content. In some cases air content continued to increase even after 5 minutes of mixing. This may have been caused by the characteristics of the mixer, the sequence in which materials were batched, the time required to charge the mixer, or other parameters. In any event, achieving a batch of concrete with proper characteristics seemed to be more difficult when fly ash was being used. It also seemed that most batches with fly ash experienced a more rapid loss in slump with time than the control batches. However, no experiments were performed to study this specific topic.

CONCLUSION

Data obtained from this phase of the project suggest that the replacement of portland cement with fly ash can result in concretes very similar to Class A concrete if viewed on the basis of strength. It may be desirable to study other factors such as durability and constructability before fly ash concrete is used on a broad scale in highway construction.

REFERENCES

(1) Standard Specifications for Highway Construction. Oklahoma State Highway Commission, 1976.

(2) "Concrete and Mineral Aggregates." Annual Book of ASTM Standards. Part 14, 1980.

(3) Powers, T. C. "Studies of Workability of Concrete." Proceedings, ACI, Vol. 28 (1932), pp. 419-448.

(4) "Muskogee Ash Technical Data." Concrete Data for Class A Concrete. 2nd ed. Bryan, Texas: Consulting and Research Services, Inc., 1980.

TABLE 1

DATA FOR FRESH MIX CONCRETE COMPRISING OF FLY ASH FROM 0% TO 50% REPLACEMENT, BY WEIGHT

	Percent Fly Ash						
	0	0	10	20	30	40	50
Materials Per Cu Yd							
Cement (lb)	564	564	507.6	451.2	394.8	338.4	282
Fly Ash (lb)	0	0	56.4	112.8	169.2	225.6	282
Fine Aggregate (lb)	1226	1226	1226	1226	1226	1226	1226
Coarse Aggregate (lb)	1967	1967	1967	1967	1967	1967	1967
Air Entraining Agent (ml)	216	216	243	270	270	324	324
Water-Cement Ratio	0.48	0.48	0.40	0.43	0.41	0.44	0.39
Properties*							
Temperature (°F)	82.7	81.0	80.0	79.7	81.0	80.0	79.5
Air Content (%)	5.3	5.9	5.6	5.6	5.8	5.9	5.9
Slump (in.)	2.50	2.50	2.50	2.75	2.75	2.25	3.00
Powers Remolding Effort	40	34	55	43	37	44	33
Unit Weight (lb/ft^3)	149.0	147.0	145.8	147.0	145.8	145.6	146.4
Initial Set (h:m)	3:23	3.35	4.26	5.26	7.02	6.50	8.28
Final Set (h:m)	4.50	4.58	6.03	7.21	9.02	9.26	11:15

*These properties are the mean of readings from two different batches, except time of set, which is the average of readings obtained from three different batches.

TABLE 2

STRENGTHS OF CONCRETE COMPRISING OF FLY ASH
FROM 0% to 50% REPLACEMENT, BY WEIGHT

Strength	Age (days)	Percent Fly Ash						
		0	0	10	20	30	40	50
Compressive (psi)	7	3780	3590	3610	3460	3480	3160	2810
	14	4330	4035	4200	4350	3630	4080	3445
	28	4485	4520	4560	4190	4710	4700	4175
	90	5745	4845	5385	5720	5100	4755	4775
Flexural (psi)	7	585	575	520	565	555	530	490
	14	575	640	620	635	590	620	615
	28	635	655	670	685	670	705	650
	90	760	655	740	720	730	775	675
Splitting Tensile (psi)	7	445	420	380	315	375	345	320
	14	425	325	465	395	325	375	365
	28	465	405	445	465	420	420	415
	90	570	440	440	490	470	540	470
Modulus (ksi)	7	2750*	4780	3070*	2820*	3060*	2830*	2770*
	14	3150*	4740	3560*	4510	2980*	4780	3120*
	28	3420*	4740	3880*	4620	4400	4950	4730
	90	5140	5410	5980	5550	5340	5640	5600

*These modulus values may be in error because of a malfunctioning recorder.

APPENDIX A

SUMMARY OF TEST PROGRAM AND STRENGTH INFORMATION

Fine Aggregate

Well graded with fineness modulus = 2.72

Specific gravity (SSD) = 2.69

Specific gravity (dry) = 2.62

Absorption Capacity = 0.69%

Coarse Aggregate, No. 57

Specific gravity (SSD) = 2.76

Specific gravity (dry) = 2.81

Absorption capacity = 0.83%