CONCRETE CASE STUDY NUMBER 32 — EVALUATION OF EXPERIMENTAL INSTALLATION OF FLY ASH CONCRETE IN LOUISA

by

H. Celik Ozyildirim
Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

The objective of this study was to investigate the resistance of field concretes containing fly ash to damage from cycles of freezing and thawing as evidenced by scaling, based upon a re-evaluation of a field project. In 1955 and 1956 an experimental sidewalk, curb and gutter installation made from concrete utilizing fly ash was placed in Louisa. In this installation two levels of fly ash content were used. In one mixture 20% of the cement by weight was replaced with fly ash and in another 33% of the cement was replaced. Air contents were approximately the same. A visual examination of the installation revealed that concretes containing fly ash exhibited more scaling than did the control mixture, with the mixture having the 33% replacement scaling the most. The internal structures of cores taken from all concretes (20% replacement, 33% replacement and the control) were in good condition and no internal damage from freezing and thawing could be observed. The compressive strengths of the cores were all satisfactory.

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INTRODUCTION

There has long been considerable worldwide interest in the use of fly ash as a partial replacement for portland cement in concrete. This interest has increased because of the large amount of energy required in the production of cement. Fly ash is a waste product collected from exhaust stacks of power plants that use pulverized coal as fuel. It consists of solid or hollow spherical particles of siliceous and aluminous glass, and, in small amounts, thin walled, multifaceted polyhedrons with a high content of iron particles and irregularly shaped porous carbon.(1) The disposal of fly ash creates problems for the power plants because of environmental restrictions and high transportation costs when it must be moved any appreciable distance. However, problems associated with the disposal of fly ash can be reduced if markets for the use of this material can be found. One potential market is its use in concrete used in the construction of highway pavements and structures, which offers opportunities for achieving economy in construction and savings in energy.

Fly ash can be used to replace a portion of cement in concrete because it is a pozzolan and thus reacts with the lime generated during the hydration of portland cement in the presence of water to form cementitious products.(2) Therefore, a saving in construction costs would result, assuming that the cost of obtaining and handling the fly ash would not exceed the cost of the cement replaced, which usually is the case. Currently, an important consideration is the overall reduction in energy use since the production of portland cement, which is widely used in highway construction, requires considerable energy, while only a small amount of energy is required to make the fly ash available for use.

Additionally, good quality fly ash with a low carbon content, when used in optimum amounts, can improve the properties of portland cement concrete; i.e. it can enhance the workability of the mixture, increase the resistance of concrete to damage from sulfates, produce low heat of hydration and thermal shrinkage, reduce permeability, and inhibit the deleterious reactions between certain aggregates and alkalies in cements.[1,3] Conversely, if a pozzolan is of poor quality or if too much is used in relation to the cement content, it can reduce the rate of hardening and strength development, increase water demand and drying shrinkage, and lower resistance to freezing and thawing.

In Virginia, Type II cement has been specified for many years for use in structural and paving concrete. Type IP cement may also be used in concrete except that used for pavements or bridge decks.[4] At the Research Council a study entitled "Alternatives to Type II Cement" was conducted to investigate concrete mixtures incorporating fly ash as possible alternatives to mixtures utilizing Type II cements.[5,6] In the study, control mixtures were prepared using Types I, II and III cements, and the experimental mixtures were made of Type IP cement and Type I cement with fly ash of good quality. The results of laboratory tests indicated, in general, that concretes containing Type IP cement or Type I cement with fly ash are acceptable alternates to Type II; however, more scaling was noted for concretes containing fly ash than for the control mixtures. The laboratory studies showed a weak, porous layer at the surface of the fly ash concretes which may lead to a high degree of scaling.[6] At present, the cause of the porous layer is not known. As a result of the investigations, fly ash concrete is permitted for use in selected, nonwearing surfaces.

Because laboratory specimens of concretes containing fly ash have exhibited variable and sometimes borderline resistance to freezing and thawing in the presence of 2% NaCl, it was desired to observe the actual extent of scaling of some field concretes in which fly ash had been used. An experimental sidewalk, curb and gutter installation constructed of concrete containing fly ash and placed in Louisa in the mid-fifties was investigated, with especial attention being given to the resistance of the concrete to damage from freezing and thawing and to its susceptibility to scaling caused by deicing salts.

EARLY COUNCIL RESEARCH ON FLY ASH CONCRETE

In 1954, research on the use of fly ash as a replacement for a portion of cement in portland cement concrete mixtures was initiated at the Council by Alexander,[7] and this work was continued by Melville and Romero.[8,9,10] As a result of these laboratory studies, a field test was planned and carried out by Forrer.(11) In the laboratory tests, attention was drawn to the effects of the variability in the composition of fly ash and the amount of carbon in the fly ash on the quality of concrete.

In late 1955 and early 1956, an experimental sidewalk, curb and gutter installation utilizing fly ash was placed in Louisa.(11,12) Figure 1 shows a recent general view of this installation. The control mixtures contained 588 lb/yd.^{3} of Type II cement per cubic yard of concrete. The maximum water-cement ratio was 0.49. The mixer used had a 188-lb. capacity.

In the two experimental mixtures placed, 20% and 33% of the cement by weight was replaced with fly ash. In the entrance ways to houses and businesses, a high early strength portland cement, Type III, was utilized. All the concretes were intended to have an air content of 4%. The concretes were placed by hand, rodded with shovels, and covered with curing paper. The fly ash used had a high carbon content as indicated by loss on ignition values ranging from 9.5% to 11.4%. Such high carbon contents can cause difficulties in entraining the proper amount of air in concrete. Cylinders measuring 6 x 12 in. were prepared for compressive strength tests.

Figure 1. A recent general view of the experimental installation at Louisa.

Groups of eight cylinders were fabricated from several batches from each of the three concrete mixtures, and the results of tests on two cylinders were averaged in determining the compressive strength values at the ages of 7, 28, 90 and 365 days. For assurance, occasionally two cylinders were cast from additional batches for testing at 28 days. The test data, as given in Forrer's report, are shown in Table 1.(12)

Table 1

Compressive Strength of 6" x 12" Cylinders
(Average of Two Specimens)

Percent Fly Ash	Cylinder Group Number	Strength in psi			
		7 Day	28 Day	90 Day	365 Day
33	(10)	1605	2679	4205	5200
	(2)	1454	2748	4688	6360
	(9)	1555	2580	4157	4825
	(1)		2900		
	Average	1558	2727	4343	5462
20	(4)	2375	4180	5230	5740
	(11)	1798	3863	5255	5530
	(3)*		2840		
	(7)*		3538		
	(6)*		3010		
	(12)*		2980		
	(13)*		3400		
	Average	2087	3402	5243	5635
0	(5)	2380	3340	3515	3980
	(8)*		5390		
	Average	2380	4365	3515	3980

*Groups in which only two cylinders were cast; both tested at 28 days.

SOURCE: Reference 12.

At 7, 28, 90 and 365 days, the mixture with the 20% fly ash replacement exhibited average compressive strength values of 2,087 psi, 3,402 psi, 5,243 psi, and 5,635 psi; the mixture with 33% fly ash attained strengths of 1,558 psi, 2,727 psi, 4,343 psi and 5,462 psi for the respective time periods. The averages were based on different numbers of specimens obtained from different cylinder groups as shown in Table 1. For the control section, due to the early termination of the project, only one group of 8 specimens were prepared for testing at 7, 28, 90 and 365 days and another group of 2 specimens were cast for testing at 28 days. The group of 8 specimens for the control attained compressive strengths of 2,380 psi, 3,340 psi, 3,515 psi and 3,980 psi at 7, 28, 90 and 365 days, respectively. The additional 2 specimens for the control tested at 28 days exhibited a strength of 5,390 psi, which was much larger than the 3,340 psi attained by the other control group and increased the average value at 28 days to 4,365 psi. These results indicate that the group of 8 specimens from the control mixture had lower compressive strengths than anticipated or the group of 2 specimens had a strength higher than anticipated, possibly due to some problem with the related mixtures. The 3,340 psi attained by the control at 28 days is comparable to the 3,402 psi achieved by the batch having a 20% fly ash replacement, but higher than the 2,727 psi exhibited by the mixture with the 33% replacement. The concretes containing fly ash showed a higher rate of strength gain from 28 days to 365 days than did the control, and the mixture with the 33% replacement yielded the highest rate of increase. In summary, the results showed that at early ages of 7 and 28 days, the mixtures utilizing fly ash had lower compressive strengths than did the control, and the mixture with the 33% fly ash replacement attained the lowest value. However, at 90 and 365 days the fly ash mixtures achieved compressive strength values higher than those of the control.

These results are generally consistent with the established behavior of concrete containing pozzolanic materials. That is, the strength development is usually slower than for concrete without pozzolans, but the ultimate strength development is usually greater.

Forrer also reported results from sonic modulus tests performed to determine the durability of the concrete as evidenced by its resistance to damage from freezing and thawing.[11] One 3 x 3 x 16 in. beam from the control mixture and two beams from both the 20% and 33% fly ash replacement mixtures were prepared. Specimens were frozen overnight and thawed in a water bath during the day. At 180 cycles an average sonic modulus of elasticity of 5.22×10^6 lb./in.^{2} was recorded for the 20% fly ash mixture; 4.82×10^6 lb./in.^{2} for the 33% fly ash mixture; and 4.47×10^6 lb./in.^{2} for the control. All these values indicate a sound internal structure.

The curbs and gutters of the experimental installations at Louisa were subjected to salt applications used for deicing since use of such salts is a routine Departmental procedure. Normally salt would be applied to the sidewalks to facilitate pedestrian traffic and sometimes salt could be carried to them from the road surface.

OBJECTIVE AND SCOPE

The objective of the recent evaluation of the Louisa installation was to investigate the resistance of field concretes containing fly ash to damage from freezing and thawing as evidenced by scaling after 23 years in service.

The investigation was limited to an inspection of the project and strength tests and petrographic examinations of several cores.

PROCEDURE

A visual investigation of the installation was made. Ten 4-in. cores were obtained from the gutters since gutters would be exposed to considerable amounts of salt. From both the control and high early strength sections 2 cores were drilled and from each of the 20% and 33% fly ash replacement sections 3 cores were obtained. Seven of the cores were tested for compressive strength. The tops and the bottoms of these cores were cut to obtain level ends. Then all 10 cores were cut vertically and one side polished for microscopic examination and air content and spacing factor determinations by linear traverse analyses.

RESULTS

From the visual investigation, the concrete surfaces were rated in accordance with ASTM C672. The condition of the surface was rated as: no scaling (0); very slight scaling (1); slight to moderate scaling (2); moderate scaling (3); moderate to severe scaling (4) and severe scaling (5). The curb and gutters were rated separately from the sidewalks because of the different exposure conditions. Results of the field survey are shown in Table 2. In the curb and gutter sections, in general, the control mixtures exhibited slight to moderate scaling. The mixtures with

20% fly ash and the concretes with high early strength cement in the gutter section of the entrance ways showed moderate scaling. The 33% fly ash sections exhibited moderate to severe scaling. In the sidewalks, the controls and the concretes with 20% fly ash showed slight to moderate scaling and the 33% fly ash section exhibited moderate scaling. The concretes with the high early strength cement at the entrance ways, except in the gutters, displayed slight to moderate scaling. In general, the fly ash mixtures exhibited more scaling than did the controls with Type II cement, and the degree of scaling was directly related to the amounts of fly ash present. The concretes in the sidewalks exhibited less scaling than the concretes in the curb and gutters. Normally the curb and gutters get more saturation and salt application than do the sidewalks.

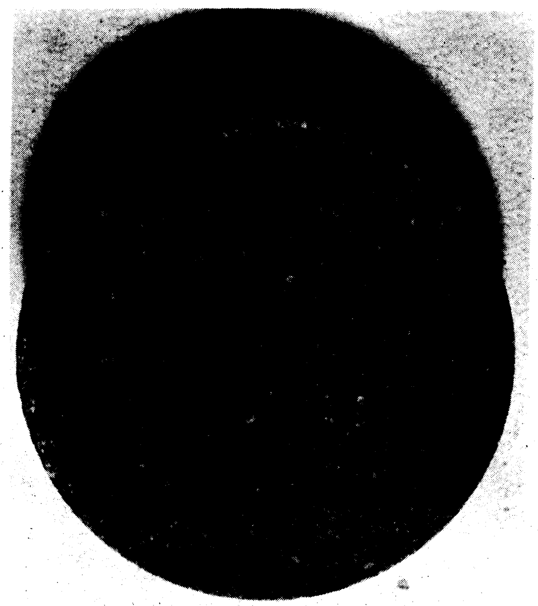
Figures 2-4 show the scaling on surfaces of cores from gutters containing control and fly ash concretes. The concretes with high early strength cement showed more scaling than did the control with Type II cement, probably because of the wear and salt deposits caused by the vehicles traveling on the entrance way or the fineness of the high early strength cement, which normally requires more water than Type II cements for the same workability.

Table 2

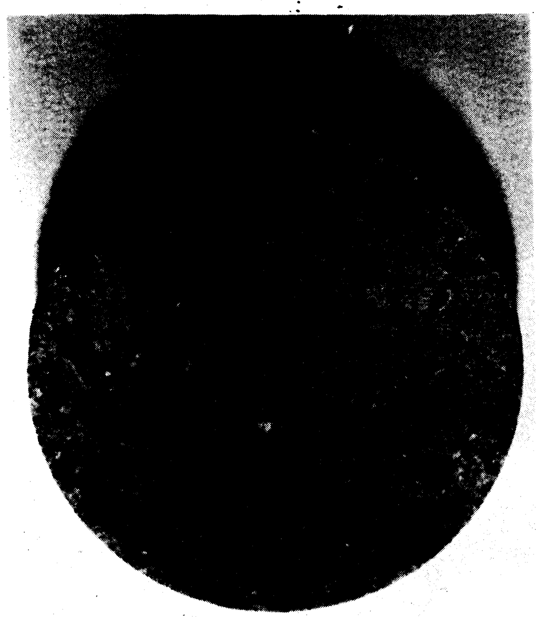
Level of Scaling of Concretes at Louisa Installation

Cement replaced by fly ash, %	CURB AND GUTTER		SIDEWALK	
	Rating	Scaling Condition	Rating	Scaling Condition
20	3	Moderate	2	Slight to moderate
33	4	Moderate to severe	3	Moderate
High early strength	3	Moderate	2	Slight to moderate
Control	2	Slight to moderate	2	Slight to moderate

The linear traverse and the compressive strength data on the cores tested are given in Table 3. The compressive strengths, taken as an average of 2 samples, were 7,330 psi for the control, 6,060 psi for 20% fly ash mixture and 7,530 psi for 33% fly ash mixture.

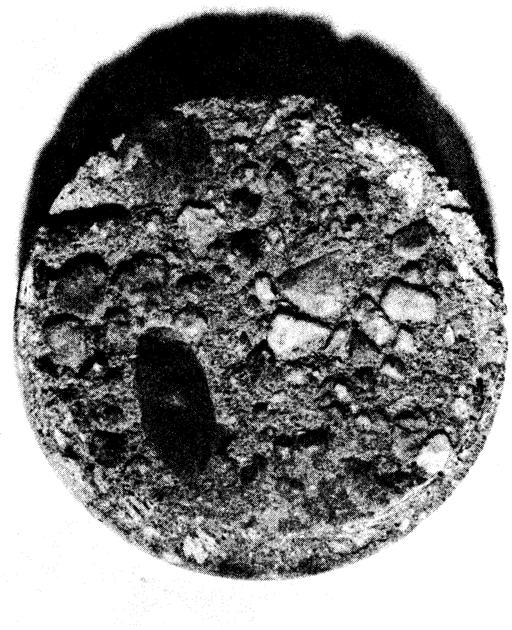


Core #9

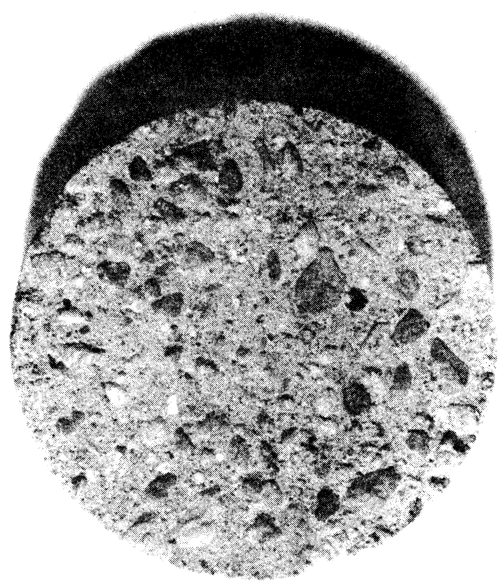


Core #10

Figure 2. Top view of the cores from the control section.

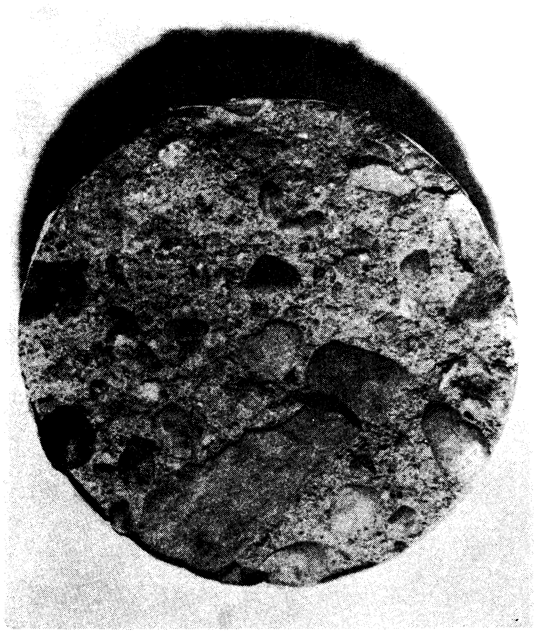


Core #1

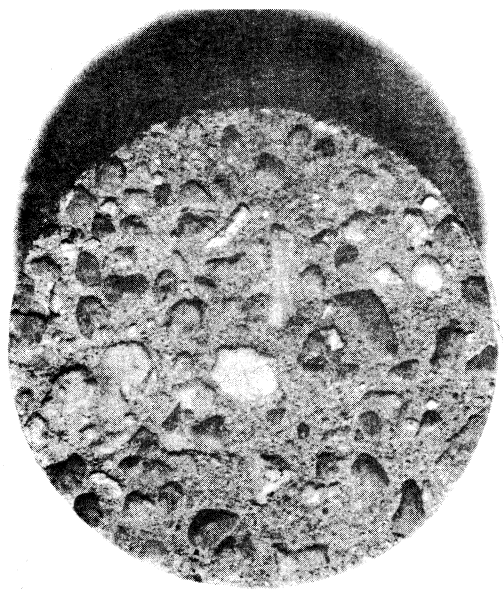


Core #2

Figure 3. Top view of the cores from the mixture with 20% fly ash replacement of cement.



Core #4



Core #5

Figure 4. Top view of the cores from the mixture with 33% fly ash replacement of cement.

Table 3

Linear Traverse and Compressive Strength Data
of the Cores from Louisa

Core	Cement Replaced by Fly Ash, %	Total Air, %	Air Voids < 1 mm, %	Spacing Factor, in.	Compressive Strength, psi
1	20	5.4	3.2	0.0064	6,140
2	20	4.5	2.9	0.0068	5,980
3	20	3.3	1.6	0.0142	---
	Avg.	4.4	2.7	0.0091	6.060
4	33	3.4	1.4	0.0143	6,950
5	33	5.1	1.3	0.0162	8,110
6	33	4.7	2.5	0.0167	---
	Avg.	4.4	1.7	0.0157	7,530
7	High early strength	3.4	2.5	0.0085	---
8	High early strength	5.2	2.8	0.0111	6,990
	Avg.	4.3	2.6	0.0098	6,990
9	Control	3.3	2.0	0.0092	7,210
10	Control	3.8	2.6	0.0086	7,450
	Avg.	3.6	2.3	0.0089	7,330

For adequate protection from damage caused by freezing and thawing normal portland cement concrete should have a void system with a spacing factor of 0.008 in. or less. As shown in Table 3, concretes with 33% replacement of cement with fly ash have spacing factors ranging from 0.0143 in. to 0.0167 in., the highest obtained for any of the samples. This result is consistent with the moderate to severe scaling observed on the sections from which they were obtained. Two of the 3 cores with 20% replacement have the lowest spacing factors of 0.0064 in. and 0.0068 in. but the third core had a significantly greater spacing factor of 0.0142 in. The average spacing factors were 0.0089 in. for the control, 0.0091 in. for the 20% replacement mixtures and 0.0157 in. for the 33% mixtures. The concretes utilizing high early strength cement had a value of 0.0098 in. The average total air contents were 3.6% for the controls and 4.4% for both the 20% and 33% fly ash replacements. The air voids less than 1 mm in diameter were 2.3% in the controls, 2.7% in the 20% replacement and 1.7% in the 33% replacement. The average spacing factors were higher than the desired 0.008 in. and are consistent with the low air contents. The results indicate that the air void systems found should provide comparable protection from freezing and thawing in both the control concrete and 20% replacement, assuming similar exposure conditions. However, it was noted that the scaling was higher in the 20% fly ash samples than in the control (see Figures 2 and 3). The results also indicate that the concrete with 33% fly ash should have the greatest scaling, which is consistent with the results from the visual observation.

One difficulty in conducting the linear traverse analysis with fly ash concrete should be noted. A recent investigation of concretes utilizing fly ash indicated that it is difficult to differentiate between the hollow fly ash particles and air bubbles.(6) The hollow fly ash particles have thin shells that blend well with the matrix in the portland cement concrete. The sizes of these fly ash particles are comparable to those of small air entrained bubbles. Their contribution to the total air content would be small but it is conceivable that they can make the computed spacing factor considerably lower than the actual spacing factor. Thus, for concretes containing fly ash, it is difficult to draw conclusions based on linear traverse analyses alone. However, the microscopic examination of 3 cores representing 20% and 33% replacements and the control, respectively, that were not tested for compression indicated that the internal structure of the concrete was sound and no unusual microcracking had occurred, even though the cores exhibited varying degrees of scaling. This result is in agreement with the high compressive strengths obtained on all the cores tested. Microcracks are expected to occur in concrete samples that are critically saturated and deficient in air when they are subjected to cycles of freezing and thawing, and a large number of microcracks would normally lower the compressive strength of concrete.

CONCLUSIONS

The concretes with fly ash showed more scaling than did the control, even though the air contents were approximately the same. The concrete with 33% of the cement replaced with fly ash showed more scaling than did the 20% fly ash mixture. The internal structure of each of the 3 cores that were not subjected to compression, representing 20% and 33% cement replacements and the control, were in good condition without apparent unusual microcracking. Therefore, it appeared that no internal damage from freezing and thawing had occurred. This conclusion is also substantiated by the high compressive strengths obtained on all the cores tested.

The concretes containing fly ash attained satisfactory strength levels. Even though at early stages the compressive strengths were low in the fly ash concretes, in general, the ultimate strengths were high compared to those of the controls.

Consequently, it is concluded that concrete containing fly ash as a replacement for part of the cement at optimum amounts for strength and durability can provide adequate service over a long period of time, even though more scaling than observed for ordinary concretes may occur.

RECOMMENDATIONS

Concretes containing fly ash should be utilized in field projects, provided stringent controls are placed on obtaining correct or specified amounts of entrained air for the mixtures that are to be exposed to deicers, so that a better understanding of the resistance of these concretes to scaling can be obtained. It is debatable if fly ash concretes scale more than controls as a result of a weak, porous surface or difficulty in entraining adequate air. A laboratory study to investigate the surfaces of specimens with different proportions of fly ash would be desirable.

ACKNOWLEDGEMENTS

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