Reclaimed Fly Ash As Select Fill Under PCC Pavement

KENNETH L. BERGESON AND DAN MAHRT

With the support of the Iowa Fly Ash Affiliates, research on reclaimed fly ash for use as a construction material has been ongoing since 1991. The material exhibits engineering properties similar to those of soft limestone or sandstone and a lightweight aggregate. It is unique in that it is rich in calcium, silica, and aluminum and exhibits pozzolanic properties (i.e. gains strength over time) when used untreated or when a calcium activator is added. Reclaimed Class C fly ashes have been successfully used as a base material on a variety of construction projects in southern and western Iowa. Many of the soil types encountered for highway projects are unsuitable soils under the current Iowa DOT specifications. The bulk of the remaining soils are Class 10 soils. Select soils for use directly under the pavement are often difficult to find on a project, and in many instances are economically unavailable. This was the case for a 4.43-mile grading (STP-S-90(22)-SE-90) and paving project in Wapello County. They supported the use of reclaimed fly ash for a portion of the project. Construction of about three miles of the project was accomplished using ten inches of reclaimed fly ash as a select fill beneath the PCC slab. The remaining mile was constructed according to the original design to be used as a control section for performance monitoring. The project was graded during the summers of 1998 and 1999. Paving was completed in the fall of 1999. This paper presents the results of laboratory and field testing during construction.

INTRODUCTION

Reclaimed hydrated fly ashes are produced at sluice pond disposal sites at generating stations burning sub-bituminous coals (*1*). Raw Class C fly ash is collected from the electrostatic precipitators at the power plant. If the supply of the raw fly ash exceeds demand, the excess raw fly ash is transported to the sluice pond or other disposal site. At a sluice pond site, the raw fly ash is dozed into the sluice pond where it hydrates to form a cementitious, solid mass to create a working platform where additional raw fly ash is spread, water is added, and the product is compacted. Once the ash has hydrated, it is reclaimed using conventional recycling-reclaiming equipment to pulverize the material. The reclaimed fly ash is then stockpiled on site, ready for use as a construction material.

This project begins at the Alliant Utilities generating station in Chillicothe, Iowa and runs west to the Monroe-Wapello county line. The road will carry a significant amount of semi-tractor trailer traffic hauling coal from the generating station to a Cargill corn processing plant in Eddyville, Iowa. Select subgrade soils are not available on site, thus the pavement was to be constructed directly on a Class 10 subgrade. Approximately 3.1 miles out of the 4.43-mile project was constructed with 10 inches of reclaimed fly ash select fill beneath 9-1/2 inches of PCC pavement. The remainder of the project was constructed using typical construction practices, utilizing the Class 10 soils on site, and serves as a control section for performance evaluation.

The reclaimed fly ash was constructed 12 inches thick and full width (49 feet) during the grading process. After compaction of the reclaimed fly ash fill, a two to three-inch thick temporary surfacing of crushed limestone was placed. Prior to paving, approximately two inches of the reclaimed fly ash fill was trimmed to be used for shouldering material, leaving approximately 10 inches of select fill to support the pavement. Pavement thickness designs conducted by the Iowa Concrete Paving Association resulted in an allowable thickness reduction from ten to nine inches using reclaimed fly ash select fill. The Wapello County engineer elected to use a 9-1/2 inch slab as a conservative approach.

The reclaimed fly ash fill was constructed in one twelve-inch thick lift, using a sheepsfoot roller for initial compaction. A steel or pneumatic wheel roller was used for final compaction to create a smooth surface. The reclaimed fly ash fill was specified to be compacted at ± 2% of the Standard Proctor optimum moisture content to 90% of Standard Proctor density for the bottom six inches, and 95% of Standard Proctor density for the top six inches.

CONSTRUCTION TESTING PROGRAM

Standard Proctor Testing

One-point standard Proctor testing was conducted daily to monitor variations in the reclaimed fly ash as the reclaiming depth increased. The testing was run in accordance with ASTM D698 – Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort, except the compaction samples were run at the moisture content at which they were collected, and only one compactive trial was made. Because a full suite of standard Proctor testing was completed prior to the actual construction, ranges of optimum moisture content and maximum dry unit weight were already known. Knowing the general compaction characteristics, the one-point Proctor tests were used to monitor daily variation of moisture content and dry unit weight. A summary of the results is presented in Table 1.

Moisture Content Testing

Moisture content determinations were made at least once daily during construction of the test road to ensure that the moisture content was within the specified range. During construction in the fall of 1998, moisture control was not a large problem. The fly ash that was

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Civil and Construction Engineering Department, Iowa State University, Ames, Iowa 50011.

TABLE 1 Standard Proctor Testing

	Average Standard Proctor		
Construction Period	Number of Tests	Dry Unit Weight (lb/ft^3)	Moisture Content (%)
Fall 1998	19	94.7	23.8
Standard Deviation		1.8	1.8
Summer 1999	22	93.7	24.0
Standard Deviation		2.5	2.9
Overall Average	41	94.2	23.9
Overall Standard Deviation		2.2	2.5

reclaimed was near the optimum moisture content and no water had to be added. During construction in the summer of 1999, however, the in situ moisture content of the hydrated fly ash was well below the optimum moisture content, and water had to be added to the material to increase the moisture content to near optimum. The in-situ moisture content of the hydrated fly ash during the summer of 1999 remained around 18% to19%. With an optimum moisture content near 24%, a large volume of water needed to be added to the reclaimed fly ash to increase the moisture content into the specified range. The average moisture contents of the reclaimed fly ash as placed are presented in Table 2.

TABLE 2 Moisture Content of Reclaimed Fly Ash as Placed

Construction Period	Number of Tests	Moisture Content (%)
Fall 1998	26	23.0
Standard Deviation		1.6
Summer 1999	48	23.0
Standard Deviation		2.8
Overall Average	74	23.0
Overall Standard Deviation		2.4

Particle Size Analyses

Wet sieve analysis tests were conducted daily during the construction periods to monitor changes in the gradation of the reclaimed fly ash. A summary of the results of particle size analyses completed during construction is given in Table 3.

TABLE 3 Particle Size Distribution of Reclaimed Fly Ash

		Percent Passing Sieve						
Construction Period	Number of Tests	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8
Fall 1998	11	89.5	83.1	75.5	67.5	58.5	41.7	27.6
Standard Deviation		5.3	7.0	8.3	8.9	8.9	8.5	6.7
Summer 1999	21	90.7	82.0	72.2	62.7	53.3	36.9	25.0
Standard Deviation		4.3	6.0	6.8	6.3	6.9	7.2	7.1
Overall Average	32	90.3	82.3	73.3	64.4	55.1	38.5	25.9
Standard Deviation		4.6	6.3	7.3	7.2	7.6	7.7	6.9

Rubber Balloon Compaction Testing

Density tests were completed on the reclaimed ash test sections shortly after completion of sheepsfoot rolling in accordance with ASTM D2167. All results are presented based on a Standard Proctor maximum dry unit weight of 98 pounds per cubic foot, which is the highest dry unit weight obtained from all compaction tests. The selection of 98 pounds per cubic foot as the maximum dry unit weight is a conservative approach. The maximum dry unit weight of the reclaimed ash was seen to vary, but there is no trend in the variation, therefore a single value of maximum dry unit weight was selected to compute compaction at each test location. A summary of the compaction test results is presented in Table 4. Overall, good compaction was achieved, with an average of 95.9% of Standard Proctor compaction achieved for the top six inches and 90.4% of Standard Proctor achieved for the bottom six inches.

TABLE 4 Summary of Rubber Balloon Compaction Tests

Construction Period	Depth of Test	Number of Tests	g (pcf)	w (%)	Compaction (%)
Fall 1998	0-6"	30	94.4	22.1	96.3
Standard Deviation			4.8	2.2	4.9
Summer 1999	0-6"	80	93.8	20.8	95.7
Standard Deviation			3.6	2.9	3.7
Fall 1998	6-12"	5	92.4	22.6	94.3
Standard Deviation			2.4	1.1	2.5
Summer 1999	6-12"	18	87.5	21.7	89.3
Standard Deviation			3.0	1.9	3.0
Overall Average	0-6"	110	94.0	21.2	95.9
Overall Standard Deviation			3.9	2.7	4.0
Overall Average	6-12"	23	88.6	21.9	90.4
Overall Standard Deviation			2.9	0.2	2.9

Nuclear Densometer Compaction Testing

A nuclear densometer was also used to monitor compaction during construction of the test road. Density testing was conducted in accordance with ASTM D2922, and moisture testing was done in accordance with ASTM D3017. The wet density results were generally slightly higher than the dry density determined using the rubber balloon method. The moisture content determined by the nuclear gauge was always much lower than the values obtained from moisture content determinations for the rubber balloon testing. The wet density value obtained from the nuclear densometer is believed to be slightly high because of high amounts of calcium in the material. Calcium absorbs more radiation than typical soil elements, which results in a wet density reading that is higher than the actual wet density. The density readings are only slightly higher than the actual density, and can be corrected without a large loss of precision. The variation in moisture content readings was random, with no clear trends. The mechanisms controlling this phenomena are uncertain and are still under investigation. Nuclear density testing should not be used for these materials.

Dynamic Cone Penetrometer (DCP) Testing

Dynamic cone penetration (DCP) tests were conducted on freshly placed reclaimed fly ash to evaluate the short-term strength of the material. The dynamic cone penetrometer consists of a 20 mm diameter, 60° cone mounted on a steel rod. A sliding mass of 17.6 pounds is dropped 22.6 inches to drive the cone into the test material. The number of hammer drops is recorded with respect to the depth of penetration of the cone. The numerical result of the DCP test is the DCP index, which is measured in millimeters of penetration per hammer drop. The DCP index has been correlated with California Bearing Ratio (CBR), and the DCP results presented herein are given in terms of the correlated CBR. DCP testing was completed on the reclaimed ash fill at selected time periods after initial compaction to monitor strength gain of the reclaimed ash as a function of time. The reclaimed fly ash that was placed in the fall of 1998 was re-tested in the spring of 1999, approximately seven months after placement, and was tested again in the late summer of 1999, or approximately nine months after placement. The reclaimed ash that was placed during the summer of 1999 was tested prior to paving operations in the fall of 1999, about three to four months after placement. A summary of the DCP results on the reclaimed ash fill is presented in Table 5.

TABLE 5 DCP Test Results on Reclaimed Fly Ash Fill

			Average CBR from DCP Testing			
Construction Period	Age When Tested (months)	Number of Tests	Reclaimed Ash Fill 0-6"	6-12"	Subgrade Soils 0-6"	6-12"
Fall 1998	0	23	23.8	18.8	9.7	7.6
Standard Deviation			8.70	8.00	3.30	3.40
Fall 1998	7	28	57.1	34.3	20.5	8.8
Standard Deviation			16.2	18.2	17.5	3.4
Fall 1998	9	12	92.3	68.9	16.5	9.0
Standard Deviation			50.3	43.0	12.2	4.5
Summer 1999	0	79	34.0	30.5	21.9	12.6
Standard Deviation			19.9	17.3	12.8	8.2
Summer 1999	3.5	26	101.3	73.8	34.5	13.1
Standard Deviation			71.8	53.8	48.4	9.4

Strength gain of the reclaimed fly ash fill over time is shown on Figures 1 and 2. Figure 1 presents the strength gain data for material placed in October of 1998, and Figure 2 presents data for material placed in July of 1999. Both Figures 1 and 2 present the increase in the average CBR over time. Error bars are given for each data point and represent plus and minus one standard deviation from the mean and the high and low values obtained from each test set. An average strength gain of approximately 70% per month is seen in Figure 1, and an average gain of 60% per month is seen in Figure 2. A dormant period is depicted in Figure 1 that extends from the time of placement until approximately April of 1999. This dormant period occurs because the ambient temperatures are too low for strength gain to take place in the fly ash. Fly ash needs available water and heat to gain strength. When temperatures are below freezing, pozzolanic reactions and strength gain stop, thus only minimal strength gain is expected between approximately October and late March in the Midwest because temperatures are frequently below freezing in this time period.

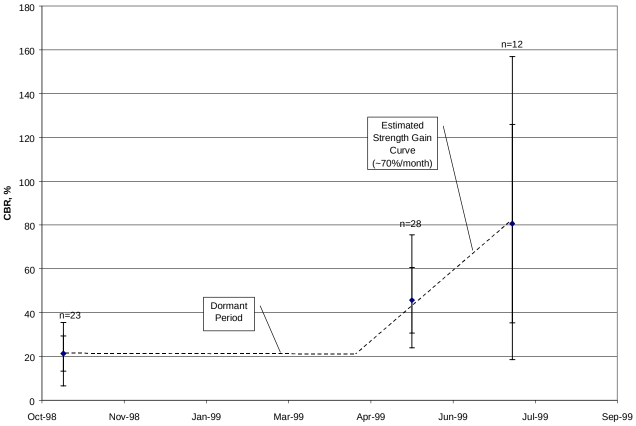

FIGURE 1 Strength gain of reclaimed fly ash fill placed in October 1998

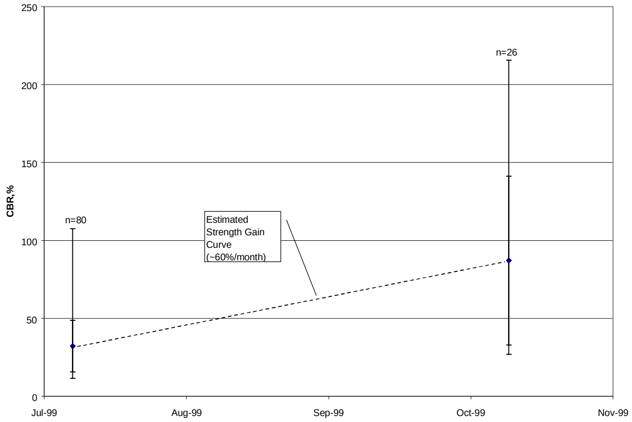

FIGURE 2 Strength gain of reclaimed fly ash fill placed in July of 1999

Dynamic cone penetration testing was also completed on the control section of the test project at different times of the year to determine the seasonal variation of CBR. The average DCP results for each test period are presented in Table 6. It is seen that the overall average CBR of the subgrade soils is 8.0%, with seasonal variation taking the CBR at the top six inches down to 4.2%. Many of the CBR values obtained are less than 6%, which is generally regarded as the minimum CBR to support construction equipment without rutting and shear failure of the subgrade soils (*2*).

TABLE 6 DCP Test Results on Control Section

		Average CBR from DCP Testing				
Construction Period	Number of Tests	0-6"	6-12"	12-18"	18-24"	Average
Late Fall 1998	22	5.0	7.2	9.5	9.7	8.0
Standard Deviation	2.0	2.9	4.0	3.7	2.7	
Late Spring 1999	22	4.2	4.5	6.2	8.0	5.7
Standard Deviation	1.7	3.0	3.3	4.4	2.3	
Late Summer 1999	8	19.8	16.1	13.0	9.3	14.5
Standard Deviation	5.5	5.6	5.9	4.7	4.1	
Overall Average	52	6.9	7.4	8.6	8.9	8.0
Overall Standard Deviation	2.4	3.3	4.0	4.2	2.7	

CONSTRUCTION

Fall 1998 Construction

Construction of the test road using reclaimed fly ash fill began on October 16, 1998. A total of 11 working days were used to construct a one-mile portion of the test road from station 0+00 to station 56+00. A total of 16,510 tons of reclaimed fly ash were placed, slightly higher than the 16,000 ton estimate. The peak production for this period was 7.6 stations, or 2,240 tons, which was placed on October 29. An average of 5.1 stations per day, or 1,500 tons was constructed per day for this construction period.

Summer 1999 Construction

Iowa State researchers met with representatives from the Wapello County Engineer's Office, ISG Resources (the select fill and raw fly ash supplier) and the earthwork contractor on June 24, 1999 to devise a plan for the final stages of select fill placement. The main goal of the meeting was to determine a course of action to follow if problems with extremely soft subgrade and soft sections of select fill were encountered. Iowa State researchers ran DCP tests on the several areas of the subgrade, and suggested that five areas in particular, as shown in Table 7, be stabilized with raw class C fly ash before placing any select fill. The Wapello County Engineer's office elected to stabilize three of these areas, as shown in Table 7. It was further decided that construction would begin at the east end of the project, proceeding westward, running the loaded haul units over the select fill to achieve further compaction.

TABLE 7 Summer 1999 Subgrade Instability Areas

Subgrade Instability Areas	Fly Ash Stabilization
Station to Station	Station to Station
138+00 to 141+00	139+00 to 140+00
141+00 to 144+00	141+00 to 144+00
174+00 to 178+00	Not Stabilized
184+00 to 188+00	Not Stabilized
205+00 to 208+00	205+00 to 208+00

Construction of the final two miles select fill began on July 13, 1999 at station 231+00. The work progressed westward to station 96+00, and finally commenced by completing stations 231+00 to 236+00. A total of 140 stations were constructed in 22 working days, for an average of 6.4 stations constructed per day. A total of 42,894 tons of reclaimed fly ash fill was placed during this time period, for an average of 306 tons per station. The select fill placement was completed on August 19, 1999.

Fall 1999 Paving

Paving operations began for the road in late September of 1999 and were completed in October of 1999. No problems were encountered that were directly related to the select fill material. Some areas of instability did develop in the select fill under traffic from loaded concrete trucks, and these areas were moistened and re-compacted with a vibratory steel-wheel roller prior to paving. Most of the unstable areas that were present at this time occurred at earlier stages of construction likely due to soft subgrade conditions, but had since "healed", only to reappear under the heavy concrete trucks.

CONCLUSION

From the testing results and research done on this project, it appears that reclaimed fly ash is a suitable material to be used as a select fill on certain projects. The reclaimed fly ash fill is inexpensive compared to typical pavement base materials and unique in that it will gain strength over time.

From a construction standpoint, there are a few precautions that must be taken and a few general guidelines to follow that are somewhat different than those typically encountered. Moisture control of the reclaimed fly ash is one of the most important facets of construction with this material. As with any soil, when the moisture content is not in the optimum range specified compaction is typically not achieved and strength is decreased. When working with reclaimed fly ash in the fall of the year, it is also important to realize that the material will not likely gain strength until the next year. This is an important fact to consider when a design value of CBR or modulus of subgrade reaction is used that is dependent on some strength gain of the material. For compaction, a heavy sheepsfoot roller, preferably vibratory, should be used for initial compaction. Final compaction should be achieved using a smooth-wheel roller such as a steel-drum roller or a pneumatic roller. The smooth wheels on these rollers smooth the surface of the reclaimed fly ash so that water will run off and not penetrate the material. Temporary surfacing material should be placed shortly after finish rolling the reclaimed fly ash pad. It should also be noted that although the reclaimed fly ash gains strength over time, it is not able to bridge extremely soft soils. If soft soils are encountered on a site, they should first be stabilized or replaced before placing reclaimed ash on top of them.

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