TRC 76

USE OF FLY ASH IN HIGHWAY CONSTRUCTION

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FINAL REPORT
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by

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Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration

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This project was instituted to examine the use of fly ash in highway construction. Fly ash is considered a waste by-product of coal-burning power plants but if properly incorporated, it could provide a reasonable substitute to dwindling construction material.

This report deals with the laboratory analysis of pressure grouting characteristics using fly ash. The results indicate three to three and one-half parts fly ash to one part Portland cement provide higher 7-day compressive strengths. Another indication is that grouting below slab temperatures of 55°F should not be allowed.

Two other reports pertaining to this research have already been prepared. "Concrete Mix Design with Fly Ash" was prepared in cooperation with the University of Arkansas at Fayetteville and "Portland Cement Concrete Base Using Fly Ash - Job #60023", provided further information on this subject. These reports are available upon request.

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SUMMARY

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METRIC CONVERSION TABLE

SYMBOL	KNOWN UNIT	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	30.48	centimeters	cm
ft	feet	0.30	meters	m
yd	yards	0.91	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.45	square cm	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.84	square meters	m^2
mi^2	square miles	2.59	sq. kilometers	km^2
	acres	0.40	hectares	ha
	acres	4046.87	square meters	m^2
		VOLUME		
in^3	cubic inches	16.39	cubic cm	cm^3, cc
ft^3	cubic feet	0.03	cubic meters	m^3
ft^3	cubic feet	28317.0	cubic cm	cm^3, cc
yd^3	cubic yards	0.76	cubic meters	m^3
gal	gallon (U.S.)	3.79	liter(1000 cc)	l
qt	quart (U.S.)	0.95	liter	l
oz	ounce fluid)	29.57	cubic cm	cm^3, cc
		WEIGHT		
lb	pound(avoirdupois)	0.45	kilogram	kg
lb	" "	453.59	grams	g
oz	ounces(")	28.35	grams	g
	short ton(2000 lb)	0.91	tonnes(1000kg)	t
		FORCE, PRESSURE		
lbf	pounds-force	4.45	newtons	N
psi, lbf/in^2	pound-force/square inch	6.89	kilopascals	kPa
	foot of water(39.2 ^{o}F)	2.99	"	kPa
	inch of mercury(32 ^{o}F)	3.39	"	kPa
		ANGLE		
^{o}	degrees	0.017	radians	rad
'	minutes	2.91×10^{-4}	radians	rad
"	seconds	4.85×10^{-6}	radians	rad
		TEMPERATURE		
^{o}F	degrees Fahrenheit	$t\,^{o}C=(t\,^{o}F-32)/1.8$	degrees Celcius	^{o}C
^{o}C	degrees Celcius	ADD 273.15	degrees Kelvin	^{o}K

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Introduction

Fly ash is a powdery by-product of the coal combustion process, usually associated with electric power generating plants, and is recovered from flue gases. The chemistry of fly ash is such that in the presence of lime and moisture, pozzolanic properties are exhibited, i.e., cementitious products are produced which result in a material of increased strength and durability. These properties make some fly ashes suitable for use as a supplement or replacement for lime and/or portland cement in various construction materials.

Arkansas has available five sources of fly ash, each having its inherent chemical and physical composition. These sources include: White Bluff and Newark, owned and operated by Arkansas Power and Light Co.; Gentry and Casson, owned and operated by Gifford Hill Co.; and the Oklahoma Gas and Electric (OGE) plant.

As a result of several sources available and the increase in amount of pavement rehabilitation, the Arkansas Highway and Transportation Department initiated this research project in the summer of 1983 to study various combinations and percentages of fly ash and portland cement for pressure grouting mixes. This report summarizes the various materials and test results.

Materials

Pressure grout for pavement undersealing consists of fly ash, Portland Cement and water. The materials are blended together to obtain a flowable mixture which can be pumped through a 2 inch drill hole in the concrete pavement to voids below the pavement.

The following paragraphs will summarize the source of each material.

Water

Water used shall be clean, potable and free from injurious amounts of oil, salts or other deleterious substances. The water used for this project met all applicable requirements of Section 501 of the Arkansas State Highway and Transportation Department's 1978 Standard Specifications for Highway Construction and was obtained from the City of Little Rock's Water Supply System.

Portland Cement

Portland Cement was obtained from two sources which are most commonly used and readily available within the State of Arkansas. Both sources meet the applicable requirements of Section 501 of the Standard Specifications.

Ideal cement was obtained from Ideal Cement Company in Okay, Arkansas. The results of physical and chemical tests of a typical sample of Ideal cement are shown in Figure 1. This sample complied with AASHTO Specification M85 for Type I Portland cement.

Foremen cement was obtained from Arkansas Cement Corporation at Foreman, Arkansas. The results of physical and chemical tests of a typical sample of Foreman Cement are shown in Figure 2. This sample complied with AASHTO Specification M85 for Type I Portland cement.

Fly Ash

Fly ash was obtained from five separate sources which are available to Arkansas. All five sources met ASTM C618 Class "C" fly ash specifications. The fly ash sources used and locations are as follows:

White Bluff fly ash is produced at the Arkansas Power and Light's coal fired generating plant at White Bluff near Redfield, Arkansas.

Newark fly ash is produced at the Arkansas Power and Light's coal fired generating plant at Newark near Newport, Arkansas.

Gentry fly ash is produced at the Gifford Hill coal fired generating plant at Gentry, Arkansas.

OGE fly ash is produced at the Oklahoma Gas and Electric coal fired generating plant at Muskogee, Oklahoma.

Casson fly ash is produced at the Gifford Hill coal fired generating plant at Casson, Texas.

Initial Investigation

In 1982 and 1983, when this project was initiated, very little pavement undersealing was being performed in Arkansas with the exception of district maintenance work. Therefore, an investigation was performed to determine what materials were being used and the blends of each material, from all ten districts. The Districts that performed undersealing operations used a sandy-silty native soil and cement at the following proportions:

District	Mix
1	0.5 bags cement/yd^3 soil
2	1.5-2.0 " " " "
3	7.0 " " " "
4	3.0 " " " "
5	3.0-4.0 " " " "
6	1.0 " " " "
7	2.0-3.0 " " " "
8	1.8 " " " "
9	No operation
10	4.0 bags cement/yd^3 soil

Unconfined compressive strength samples were molded with various mixtures of cement, fly ash and native soil. The results of these tests are shown in Table 1. The 7-day compressive strengths ranged from 16 psi for 3 bags fly ash : 2 bags Portland cement : 1 yard of sand to 104 psi for 3 bags Portland cement : 1 yard sand.

From the results of these initial tests and an article published in Transportation Research Record (TRR) No. 800, a testing program was established for all pressure grouting jobs.

Testing Program

A testing program was established to determine criteria for a pressure grouting mixture. The tests included flow cone, set times, compressive strengths, and durability testing. From the results of TRR No. 800 and information from other State Highway Departments, testing was performed on various mixtures of fly ash, Portland cement, admixtures, and water.

Mixture

The various mixtures of fly ash and Portland cement consisted of 2:1, 3:1, 3.5:1 and 4:1 parts of fly ash to parts of Portland

Ratio Agent(s)/Soil FA=Fly Ash PC=Portland Cement YS=Cu.Yard Soil	7 Day Compressive Strengths 4" Dia. Spec. 4-Hour Soak	7 Day Vacuum Sat.Strengths 4" Diameter Specimens	Wet-Dry Durability Approx.%Loss/ Cycles	Freeze-Thaw Durability Approximate %Loss/Cycles	Cube Strength Dry Cure PSI/days cure	Cube Strength Wet Cure PSI/days cure	Rating In Relation to Other Mixtures
1 FA 1 YS	Dissolved in Soak	3	100%/0 cycles	100%/0 cycles	0/1 7/2 0/5	0/1 0/2 0/5	Poor
2 FA 2 PC 1 YS	29	27	Sample Broke Apart No Test	66% @5 cycles	43/1 64/4 55/5	17/1 23/4 19/5	Poor
3 FA 1 PC 1 YS	16	15	100%/0 cycles	100%/3 cycles	No sample	No sample	Poor
1 FA 1 PC 1 YS	115	67	20%/12 cycles	15%/12 cycles	70/1 87/2 71/5	24/1 41/2 57/3	Fair
5½ FA 1 PC ½ YS	33	35	60%/10 cycles	35%/12 cycles	44/1 44/2 45/5	14/1 17/2 19/5	Poor
4 PC 1 YS	50	56	50%/3 cycles	50%/5 cycles	11/1 32/4 24/5	1/1 3/4 5/5	Poor
2 PC 1 YS	68	83	35%/12 cycles	15%/12 cycles	30/1 61/2 76/3	71/1 102/2 101/3	Fair
3 PC 1 YS	104	103	5%/12 cycles	15%/12 cycles	12/1 23/2 35/3	23/1 43/2 59/3	Fair (Best Overall)
1 PC 1 YS	43	44	Broke Apart/ 1 cycle	30%/7 cycles	31/1 49/2 49/3	11/1 17/2 22/3	Poor
7 PC 1 YS	44	43	35%/6 cycles	85%/8 cycles	66/1 76/2 58/5	22/1 37/2 62/5	Poor

One 6" Diameter Cylinder - 12" long - was tested for mixture - 1 PC 1 YS
Molded 4/13/82. Tested 10/26/82. Approximately 6 months = 175 psi - dry cured.

Table 1: LABORATORY RESULTS OF MAINTENANCE MIXES

cement. Each batch consisted of 12,000 grams dry weight of solids. The proper proportions of fly ash and Portland cement were thoroughly mixed before adding water.

The required amount of water to produce a time of efflux of 10 to 25 seconds was poured into a 5-gallon plastic bucket, then the pre-mixed fly ash and Portland cement were added in three increments. A hand-held electric drill with a paint mixing attachment was used to continuously mix the sample as the fly ash and cement were being added. After the last increment was added, the sample was mixed for 3 minutes. Immediately after mixing, a temperature was taken and three consecutive flow cone readings were performed. The average of the three readings was specified to be between 10 and 25 seconds. Once the flow has been adjusted properly the sample is molded into 4 in. x 5 in. specimens for 24 hr., 4-Day and 7-Day compressive strengths and set times.

Durability samples were also molded on a few samples but were later suspended due to the difficulty that all of the moisture could not be extracted from the specimens to determine an accurate percentage wear loss.

Testing Procedures

Compressive Strengths

A total of 27 specimens were molded for 24 hour, 4-day and 7-day compressive strengths. Three specimens from each time group were cured at the following temperatures: Moisture Closet (72°F), Refrigerator (45°F), and variable outside temperatures located on dock of Materials and Research laboratory.

Set Times

Two types of set times were performed on each mixture and curing condition. One method was the Gilmore Needle (AASHTO T-154) which consists of a small sample which was cured under the previous stated conditions. A needle was used to penetrate into the sample at various times until there was no penetration. The time was then recorded for set. The second method, developed for this project, determined the temperature and consistency of the interior of the specimen.

Test Results

The results of all tests are shown in Table 2. The set times ranged from 20 hours to 70 hours depending on the mix and curing conditions. The compressive strengths were higher for specimens cured in the moisture closet. Each compressive strength shown in Table 2 is an average of three specimens. The specimens cured in the refrigerator and on the dock were considerably weaker than the specimens cured in the moisture closet.

Additives

Various air entraining agents or water reducers were used with a 3 part fly ash to 1 part Portland cement mixture to determine their effects on the mixture. Additives that were used include 344N, WRDA-19, and LL.

The additives were added to the mix water before the solids were introduced. The results of these tests are shown in Table 2. As set time decreased, the 7-day compressive strengths also decreased. As a result of these tests, further testing with additives was suspended.

Blend No. & Composition	Date Mixed all 3 Minutes	Temperatures of Room/Water/Mix	Flow Cone Avg. of 3 (Sec.)	Set Times Moist Cured Initial/Final (Minutes)	Times Air Cured Initial/Final (Minutes)	7 Day Compressive Strengths Avg. (psi)	28 Day Compressive Strengths (psi)	Shrink / Swell Avg. (Inches)	Comments
B-1 3FA:1PC 33% H_2O	1/5/84	72/70/72	13.2	No sample	95/235	1540	No sample	0.05 Est/NM	No Measurement
B-2 3FA:1PC 1%LL 33% H_2O	1/6/84	76/74/73	10.9	137/182	107/157	120	No sample	NM/NM	No Measurement
B-3 3FA:1PC 0.1% 344N 33% H_2O	1/9/84	74/68/70	12.1	185/225	215/255	484	No sample	0.05 Est/0.0	Discontinued FT at 7 cycles-falling apart
B-4 3FA:1PC 1% LL 0.4% 33% H_2O 344N	1/10/84	74/75/74	12.0	162/182	158/176	180	No sample	NM/NM	No Measurement
B-5 3FA:1PC 32% H_2O	1/11/84	71/72/71	16.1	345/1515	205/270	1826	No sample	0.05/0.0	Discontinued FT at 6 cycles-falling apart
B-6 3FA:1PC 1%LL 32% H_2O	1/12/84	72/73/70	11.2	180/340	162/300	62	485	0.0/0.34	Note the swell
B-7 3FA:1PC 0.4% 344N 32% H_2O	1/13/84	73/73/70	11.5	140/185	135/180	400	2189	NM/0.00	
B-8 3FA:1PC 1%LL 0.4% 344N 31% H_2O	1/16/84	70/73/69	12.2	190/230	187/225	163	199	0.0/0.16	
B-9 3FA:1PC 1%LL 32% H_2O	1/25/84	74/70/70	11.1	162/375	155/225	88	1025	0.0/0.15W*	First time weighed. Lifted small weight & plastic cover & swelled at bottom
B-10 3FA:1PC .073%LL 32% H_2O	1/26/84	72/75/72	14.2	435/1345	175/405	1659	4405	.05/W	Plastic Plates & approx. 50# Wt.
B-11 3FA:1PC .25%LL 30% H_2O	1/27/84	75/71/71	13.9	240/310	210/280	333	6008	.00/W	
B-12 3FA:1PC 15%LL 29% H_2O	1/30/84	71/73/71	17.7	240/330	167/295	497	6923	.00/W	
B-13 3FA:1PC 32% H_2O	1/31/84	75/72/72	15.3	230/340	165/265	1293	5909	.03/W	Note the shrink
B-14 3FA:1PC 33% H_2O 0.85% WRDA-19	2/7/84	72/75/71	10.2	Estimated 495/675	Estimated 375/555	298		.11/W	High shrink
B-15 3FA:1PC 29% H_2O 0.24% WRDA-19	2/8/84	73/74/72	14.7	158/278	123/218	1225		.01/W	
B-16 3FA:1PC 30% H_2O 0.25% 344N	2/16/84	74/74/74	13.7	Estimated	Estimated	616			

Table 2: FREEZE/THAW VACUUM/SATURATION RESULTS

Conclusions

1. In all mixtures the 7-day compressive strengths of 3:1 and 3.5:1 produce higher strengths.
2. The set times were much longer for samples cured in the refrigerator and on the dock than in the moisture closet.
3. Additives used to help reduce set times during colder weather were successful, but they also drastically reduced the 7-day compressive strengths.
4. Curing temperature under the pavement slab is a major factor that affects grout mixture performance.

Recommendations

On the basis of the limitations of the test procedures and for the range of materials and conditions utilized in this investigation, the following recommendations are warranted:

1. Submit proper amounts of fly ash and Portland cement to the Materials and Research Laboratories for a pressure grout design.
2. Grouting of concrete pavements with slab temperature below 55°F should not be allowed.
3. Specify a minimum of 4 days for proper curing of the grout.