Lignite Fly Ash Concrete Highway Pavement—A 15-Year Performance History

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A research study was conducted at Twin City Testing Corporation in 1973, in cooperation with the North Dakota State Highway Department and the FHWA. The purpose of the study was to determine the effect on properties and performance of paving concrete with lignite fly ash substituted for various percentages of portland cement. The test program included both laboratory and field evaluations of compressive and flexural strength and freeze-thaw durability. The good performance of this concrete after 15 years of field exposure supports the original laboratory findings. The fly ashes used in this study do not conform to certain chemical and physical requirements of the current version of ASTM C618, the national consensus specification generally used as guidance for fly ash procurement; however, the nonspecification fly ash was used in pavement construction only after laboratory testing indicated its potential for providing satisfactory performance.

In 1973, the cost of lignite fly ash in North Dakota was about half the cost of portland cement. A savings of approximately \$0.80 per cubic yard of concrete, or \$0.20 per square yard of 9-in. concrete pavement, could be realized by replacing 15 percent of the portland cement with fly ash. However, there had been reluctance to use fly ash in paving concrete because of uncertainty concerning the effect of fly ash on the scaling resistance of such concrete when subjected to freeze-thaw cycles in the presence of deicing salts. Phase 1 of this study comprised laboratory testing to determine the effect on fresh and hardened concrete properties of lignite fly ash substituted for various percentages of portland cement; Phase 2 comprised laboratory and field testing of paving concrete installations for a freeway ramp in the fall of 1973, and a 10-mi section of I-29 south of Fargo, North Dakota, in 1974; and Phase 3 comprised an analysis to relate the performance of the paving concrete placed in Phase 2, after 15 years of exposure, to laboratory data compiled in Phases 1 and 2.

PROCEDURE

Phase 1: Laboratory Concrete

The laboratory test program included testing of control mixtures containing 5.5 bags of portland cement per cubic yard of concrete, and mixtures in which 15, 25, and 35 percent, by mass, of the portland cement was replaced with lignite fly ash from each of two sources. Compressive and flexural strengths were determined, and the air-void systems were analyzed. Resistance to rapid freeze-thaw and to deicer scaling was determined for all mixtures.

The fly ashes used in this study were supplied from two major lignite coal-fired power plants in Minnesota (Source 1) and North Dakota (Source 2). The following tables present the chemical (Table 1) and physical (Table 2) analyses of these fly ashes, together with pertinent ASTM C618 specifications for fly ash to be used as a mineral admixture in portland cement concrete.

As presented in Tables 1 and 2, the fly ashes used in this study did not conform to certain chemical and physical requirements of ASTM C618, the national consensus specification generally used as guidance for fly ash procurement; however, the nonspecification fly ash was used in pavement construction only after laboratory testing indicated its potential for providing satisfactory performance. It was found in Phase 3 that good performance of this paving concrete after 15 years of field exposure supports the original positive laboratory findings from Phase 1.

Specimens from each mixture were tested for compressive and flexural strength at ages of 3, 7, 28, and 90 days, and 1 year following laboratory moist curing. Additional specimens from each mixture were examined to determine air-void characteristics, and tests for resistance to freeze-thaw (ASTM C666) and deicer scaling (ASTM C672) were also performed for all mixtures. A description of materials used in the concrete mixtures is presented in Table 3.

Typical mixture proportions for the control concrete (0 percent fly ash) and the fly ash concretes (15, 25, and 35 percent, by mass, of the total cementitious material) are presented in Table 4. The approximate ratio, by mass, of water to cementitious material was 0.52 for all of the concrete mixtures. The average slump, air content, and unit weight of the fresh concrete mixtures are presented in Table 5.

The compressive and flexural strength test results for all concrete mixtures are presented in Tables 6 and 7, respectively.

The air contents measured in the fresh concrete mixtures are presented in Table 8. The microscopical determination of air-void content and parameters of the air-void system in hardened concrete is presented in Table 9 for each concrete mixture. The results of freeze-thaw tests are presented in Table 10.

The scaling resistance of concrete surfaces exposed to deicing chemicals is expressed in terms of visual rating numbers

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TABLE 1 CHEMICAL CHARACTERISTICS OF LIGNITE FLY ASHES

Characteristic	Source #1	Source #2	ASTM C 618
Silicon Dioxide (SiO_2)	22.17	36.86	
Aluminum Oxide (Al_2O_3)	17.57	11.87	
Iron Oxide (Fe_2O_3)	9.69	14.15	
Total Oxides (above)	49.43	62.88	50.0 Min
Sulfur Trioxide (SO_3)	7.20	2.90	5.0 Max
Calcium Oxide (CaO)	35.44	27.35	
Magnesium Oxide (MgO)	6.68	5.54	
Loss on Ignition	0.65	0.20	12.0 Max
Available Alkalies	3.48	2.56	1.5 Max

TABLE 2 PHYSICAL CHARACTERISTICS OF LIGNITE FLY ASHES

Characteristic	Source #1	Source #2	ASTM C 618
Fineness			
Blaine Sq cm/cu cm	7660	4330	6500 Min
Specific Gravity	2.66	2.59	5% Max Var
Compressive Strength of Mortar Cubes Ratio to Control at			
7 days, %	157	148	
28 days, %	120	111	
Pozzolanic Activity Index			
With Port. Cement, psi	3140	2990	
Ratio to Control at 28 days, %	58.2	55.4	85 Min
With Lime at 7 days, psi	1150	504	800 Min
Water Requirement, % of Control	95.0	93.0	105 Max
Increase in Drying Shrinking of Mortar Bars at 28 Days, %	-0.01	-0.01	+0.03 Max
Amount of Air Entraining Agent Needed in Mortar to Produce 18% Air, ml	0.40	0.39	20% Max Var

TABLE 3 DESCRIPTION OF CONCRETE MATERIALS

Material	Description
Fly Ash:	
Source #1	Ottertail Power Company - Fergus Falls, Minnesota
Source #2	Basin Electric Power Company - Stanton, North Dakota
Portland Cement	Universal Atlas - Duluth, Minnesota; ASTM C 150, Type I.
Air Entraining Agent	Protex Industries - Denver, Colorado; ASTM C 260.
Fine Aggregate	Downer Pit - Clay County, Minnesota; ASTM C 33.
Coarse Aggregate (Gravel)	Ten Acre Pit - Clay County, Minnesota; ASTM C 33.

TABLE 4 TYPICAL MIXTURE PROPORTIONS FOR CONTROL AND FLY ASH CONCRETES

Material	Amount per cubic yard
Total cementitious material	521 lb (cement plus fly ash)
Air Entraining Admixture	As required.
Fly Ash Range	0%, 15%, 25% and 35%, by mass.
Fine Aggregate	1242 lb
Coarse Aggregate (1 1/2 - 3/4")	875 lb
Coarse Aggregate (3/4" - #4)	1069 lb
Coarse Aggregate - Total	1944 lb
Water, Net	269 lb

TABLE 5 FRESH CONCRETE CHARACTERISTICS

Characteristic	Average
Slump	3 7/8 inches
Air Content	5.7 %
Unit Weight	146.3 lb/cu ft

TABLE 6 COMPRESSIVE STRENGTHS (ASTM C39)

	Average Compressive Strength Test Results, psi				
Mixture	3-day	7-day	28-day	90-day	1-year
Control	2450	3340	4530	5340	6160
15% Source #1	2470	3270	4930	5290	6050
25% Source #1	2520	3350	4330	5110	5660
35% Source #1	2410	3140	3110	4680	5320
15% Source #2	2290	3230	4440	5070	6070
25% Source #2	2180	3030	4390	4870	5860
35% Source #2	1840	2580	3500	4350	5680

TABLE 7 FLEXURAL STRENGTHS (ASTM C78)

	Average Flexural Strength Test Results, psi				
Mixture	3-day	7-day	28-day	90-day	1-year
Control	480	630	760	820	730
15% Source #1	470	605	745	745	750
25% Source #1	295	670	775	790	725
35% Source #1	450	570	740	825	780
15% Source #2	450	555	700	795	735
25% Source #2	460	525	690	795	835
35% Source #2	450	460	680	630	845

TABLE 8 AIR CONTENT OF FRESH CONCRETE

Mixture	Air Content, %
Control	5.4
15% Source #1	5.6
25% Source #1	5.6
35% Source #1	6.0
15% Source #2	5.6
25% Source #2	5.3
35% Source #2	5.7

TABLE 9 AIR-VOID CHARACTERISTICS OF HARDENED CONCRETE (ASTM C457)

Mixture	Avg Chord Intercept	Avg No. Sections	Air Void Content %	Specific Surface in^2/in^3	Spacing Factor
Control	0.0075	4.6	3.4	552.6	0.010
15% Source #1	0.0066	4.5	2.9	646.8	0.009
25% Source #1	0.0068	5.5	3.4	642.3	0.009
35% Source #1	0.0059	9.5	5.6	711.1	0.006
15% Source #2	0.0071	7.6	5.4	573.6	0.008
25% Source #2	0.0060	9.7	5.8	675.3	0.006
35% Source #2	0.0055	12.1	6.5	730.0	0.006

TABLE 10 FREEZE-THAW TEST RESULTS (ASTM C666)

Mixture	Relative Dynamic E After 300 Cycles, %	Average Weight Loss After 300 Cycles, %
Control	96	0.6
Source #1	95	0.4
Source #1	90	1.3
Source #1	89	2.3
Control	99	1.3
Source #2	98	0.7
Source #2	90	2.0
Source #2	91	1.8

as defined in ASTM C672, as presented in Table 11. The results of deicer scaling tests are presented in Table 12.

The use of lignite fly ashes from Sources 1 and 2 as various percentages of the total cementitious material in paving concrete mixtures was demonstrated by test results from Phase 1 to produce strong, durable concrete.

Phase 2: Field Concrete

Typical field test results for air content and slump are presented in Table 13. Field-cast cylinders were cured in the laboratory and tested at ages of 7 and 28 days, with strength results as presented in Table 14.

Phase 3: Pavement Evaluation at 15 Years

The majority of the paving concrete in I-29 south of Fargo, North Dakota, was placed in 1974 with lignite fly ash as 15 percent of the cementitious material, thus providing a site for direct comparison of concretes with and without fly ash. The pavement had been subjected to 15 years of traffic, deicers, plowing, and temperature extremes that ranged from −33°F to +106°F. This service history provided an excellent opportunity to observe on site the durability of concrete containing portland cement and lignite fly ash.

A general condition survey was performed on the subject paving concrete 15 years after construction and there existed no visual differences between the concretes with and without fly ash.

Four specific locations were chosen, on the basis of the availability of strength and other data for these locations from Phase 2, for extraction of core samples for determinations of field strength at an age of 15 years. The 15-year strengths are presented in Table 15 along with the compressive strengths from 7 and 28 days (Phase 2, Table 14) for comparison.

CONCLUSIONS

The use of lignite fly ashes as 15 percent, by mass, of the total cementitious material in paving concrete resulted in a strong,

TABLE 11 RATING SYSTEM FOR RESISTANCE TO DEICER SCALING (ASTM C672)

Rating	Condition of Surface
0	No scaling
1	Very slight scaling (1/8 in. depth, max, no coarse aggregate visible)
2	Slight to moderate scaling
3	Moderate scaling (some coarse aggregate visible)
4	Moderate to severe scaling
5	Severe scaling (coarse aggregate visible over entire surface)

TABLE 12 TEST RESULTS, RESISTANCE TO DEICER SCALING (ASTM C672)

Mixture	75 cycles	150 cycles	225 cycles	300 cycles
Control	0	1	2	3
Source #1	0	1	2	2
Source #1	0	0	1	2
Source #1	0	0	1	1
Source #2	0	1	2	2
Source #2	0	1	1	2
Source #2	0	1	1	2

TABLE 13 FIELD TESTS, AIR AND SLUMP

Pavement Station	Lane Direction	Fly Ash	Air Content, %	Slump, inches
872+34	North Bound	15%	2.2	1
900+15	North Bound	15%	5.5	1 1/2
926+30	North Bound	0%	5.6	1 1/4
2+62	South Ramp	15%	5.5	2

TABLE 14 LABORATORY STRENGTH OF FIELD CONCRETE

Pavement			Compressive Strength, psi	
Station	Lane Direction	Fly Ash	7-day	28-day
872+34	North Bound	15%	3930	4560
900+15	North Bound	15%	3380	4020
926+30	North Bound	0%	3990	4600
2+62	South Ramp	15%	3900	4600

TABLE 15 COMPARISON OF COMPRESSIVE STRENGTH

			Strength, psi		
			Phase 2		Phase 3
Pavement Station	Lane Direction	Fly Ash	7-day	28-day	15-year
872+34	North Bound	15%	3930	4560	7620
900+15	North Bound	15%	3380	4020	7100
926+30	North Bound	0%	3990	4600	6880
2+62	South Ramp	15%	3900	4600	6050

durable concrete pavement for I-29 south of Fargo, North Dakota, after 15 years of exposure under field conditions.

The good performance of this concrete after 15 years of field exposure supports the original laboratory findings. The fly ashes used in this study do not conform to certain chemical and physical requirements of the current version of ASTM C618, the national consensus specification generally used as guidance for fly ash procurement; however, the nonspecification fly ash was used in pavement construction only after laboratory testing indicated its potential for providing satisfactory performance.

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