ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

Progress Report

STUDY OF ST. CLAIR FLY ASH IN NON-AIR-ENTRAINED CONCRETE MADE WITH PORTLAND AND PORTLAND-SLAG CEMENTS

ONE-YEAR REPORT

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THE DETROIT EDISON COMPANY
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ABSTRACT

With increasing production and use of portland-slag cement, a study was undertaken to determine if there were an important difference between its behavior and that of normal portland cement when used in concrete containing St. Clair fly ash. Only one cement content was used, namely, 4.5 sacks per cubic yard. Three fly-ash contents as well as a control mix without fly ash were used with both types of cement.

The fly-ash mixes made with portland-slag cement generally show inferior compressive strengths to those made with normal portland cement at ages of 1 and 7 days, but usually have superior strengths at later ages through one year. The usual pozzolanic-strength gain attained when using this fly ash with normal portland cement is not realized, however, when using this ash with the portland-slag cement at ages up to one year. The observation follows that the strength of the control mixes without fly ash were about equal for the two types of cement at 1 and 7 days, but the portland-slag cement mixes had considerably higher compressive strengths at later ages up to one year.

OBJECTIVE

The purpose of this investigation is to study the properties of fly ash and concrete containing fly ash, as indicated by compressive strength, workability, durability in freezing and thawing, flexural strength, and other measures of concrete quality. The phase of the investigation covered by this report is concerned with the effect on compressive strength and workability of the use of portland-slag cement with fly ash, as compared to the use of normal portland cement with fly ash.

INTRODUCTION

To supplement their output, cement producers are now manufacturing increased quantities of portland-slag cement to increase their production without necessity for a corresponding increase of kiln capacity. By inter-grinding to sufficient fineness approximately 40 percent granulated blast-furnace slag (a product quite different from air-cooled slag such as that used for aggregate), a cement can be produced which is of equivalent strength to normal portland cement at ages up to 28 days. At later ages the compressive strength usually becomes superior to that of normal portland cement.

Pursuant to a contract between The Detroit Edison Company and the Engineering Research Institute of The University of Michigan, a study was made of the use of fly ash in concrete made with normal portland cement and with portland-slag cement. The study is of an abbreviated nature, using only one cement content, to determine if there is pronounced difference in the effect of the reaction of the two types of cement with St. Clair fly ash. The report covers such matters as mix proportioning and compressive strength of concrete through an age of one year.

Some matters pertaining to test procedures which were covered in earlier reports will be omitted here to avoid repetition. This report is exclusively concerned with St. Clair fly ash in non-air-entrained concrete. It is recommended that such concrete not be used where it will be subjected to freezing and thawing in the presence of moisture.

MIX DESIGN

The "Recommended Practice for Selecting Proportions for Concrete" (ACI 613-54), a standard of the American Concrete Institute, was used as the basis for the design of all mixes, as in previous studies. The stone contents were as recommended by the ACI in the mixes containing no fly ash, but were increased in the fly-ash mixes, taking full advantage of the added plasticity of the mortar constituent provided by the addition of fly ash.

Only one cement content, 4.5 sacks per cubic yard, was used for this work. Three fly-ash contents, 75, 150, and 200 pounds per cubic yard, were used. Additionally, mixes with no fly ash were made for comparison purposes. These ash contents were selected to provide coverage over a wide range without an excessive number of mixes. Identical series were made

with the portland cement and portland-slag cement.

MATERIALS

The concrete materials were generally the same as those used previously. The coarse aggregate was 1-inch-maximum-size natural gravel, the fine aggregate was a natural sand having a fineness modulus of 3.0, and the fly ash was from the St. Clair station. The portland cement (ASTM Type I) consisted of a blend of equal amounts of Huron, Peerless, and Peninsular brands. There was only one brand of portland-slag cement (ASTM Type I-S), Huron, available at the time this program was started. As a result, there was no opportunity for blending to balance out minor variations which may result from the cement-manufacturing process. Both types of cement were non-air-entraining.

The results of the physical and chemical tests on the two cements are shown in the Appendix in Table I-A for the portland cement and Table II-A for the portland-slag cement. Notice should be taken of the large gain in compressive strength of the mortar cubes made with the portland-slag cement between 7 and 28 days. This acceleration seems to be typical of this type of cement, but in concrete it is usually not evident until 28 days of age.

Properties of the fly ash are reported in Table III-A in the Appendix.

FABRICATION OF SPECIMENS AND TEST PROCEDURES

Methods of mixing, curing, and testing the specimens were generally the same as those used in the previous studies on concrete containing fly ash. Dry aggregates were generally used, although toward the end of the study it was necessary to use damp sand in a few of the mixes. Corrections were made in the batch weights to compensate for this moisture.

Two cylinders for each age of 1, 7, 28, and 90 days and 1 year were obtained from each batch, with two repeat batches for each variation of fly-ash content or type of cement, giving a total of six cylinders for each age and condition, as in previous studies. The cylinders were stored in the moist-fog room until the time for testing.

DISCUSSION OF TEST RESULTS

A detailed tabulation of the concrete-mix data and compressive-strength results is shown in the Appendix in Table IV-A for the mixes with portland cement and Table V-A for the mixes with portland-slag cement. Summaries of important aspects of the data have been prepared from these tables and are presented in the body of the report.

1. COARSE-AGGREGATE CONTENT

The greater amounts of coarse aggregate which were found to be workable in previous studies of fly-ash concrete with 1-inch maximum-size gravel coarse aggregate were used again. These amounts appeared to be about the maximum which would still yield workable concrete. Theoretically, the portland-slag cement, being much finer than the portland cement, should have permitted higher coarse-aggregate contents. No effort was made to force more gravel into these mixes since the amount which was used would already be considered too high by some users.

The value V_s, denoting the dry-rodded volume of coarse aggregate per unit volume of concrete, is given in Tables IV-A and V-A in the Appendix.

2. COMPRESSIVE-STRENGTH RESULTS

Average values of compressive strengths are presented in Table I. The strengths of the fly-ash mixes are presented in Table II expressed as a percent of the strength of the plain-cement control mixes, and the mixes containing portland-slag cement are also expressed as a percent of the strength of the control made with portland cement.

The fly-ash mixes made with portland cement produced results similar to those obtained previously, in that the fly ash improves the strength somewhat at all ages. There is very little difference in strength between the three fly-ash contents, in that they all had compressive strengths 24 to 47 percent over that of the control mix at all ages.

The addition of fly ash apparently does not appreciably benefit strength of concrete made with portland-slag cement. The lowest fly ash content (75 pounds per cubic yard) appears to be the most beneficial, producing strengths 5 to 12 percent above the portland-slag cement control mix, while concrete with the highest fly ash content (200 pounds per cubic yard) produced strengths ranging from 81 to 104 percent of the control.

TABLE I

SUMMARY OF RESULTS
Portland and Portland-Slag Cement With St. Clair Fly Ash

Nominal Cement Content, sk/cu yd	Actual Cement Content, sk/cu yd	Fly Ash, lb/cu yd	Net Mixing Water		Slump, in.	Compressive Strength, psi				
			lb/cu yd	gal/sk		1 day	7 days	28 days	90 days	1 year
Portland Cement (Type I)										
4.5	4.44	0	268	7.15	3.8	519	1925	3065	3805	4522
	4.44	75	251	6.69	3.6	701	2435	3844	5183	6386
	4.48	150	251	6.69	4.6	753	2483	3893	5379	6652
	4.48	200	260	6.93	4.0	698	2385	4010	5436	6533
Portland-Slag Cement (Type I-S)										
4.5	4.44	0	250	6.68	2.8	568	2035	3798	5268	6448
	4.45	75	246	6.58	4.4	598	2214	4153	5902	6973
	4.47	150	258	6.87	3.7	505	2013	4058	5884	6920
	4.47	200	270	7.21	4.8	459	1864	3873	5385	6687

TABLE II

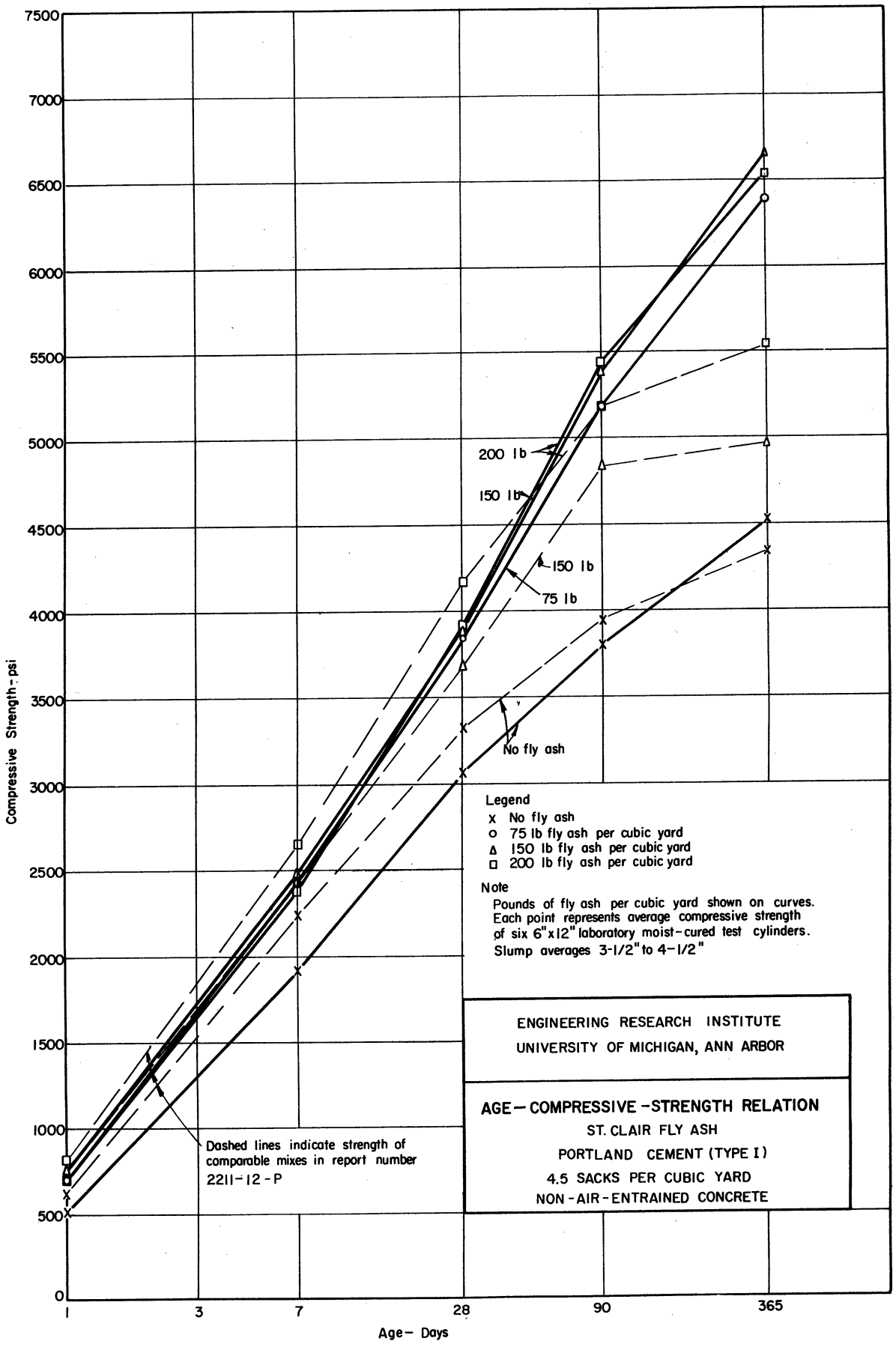
COMPRESSIVE STRENGTH OF FLY-ASH CONCRETE
EXPRESSED AS PERCENT OF PLAIN CEMENT CONTROL MIXES

Cement Content, sk/cu yd	Fly Ash, lb/cu yd	Age				
		1 day	7 days	28 days	90 days	1 year
		Percent of Portland Cement (Type I) Control				
4.5 Portland Cement (Type I)	75	135	126	125	136	141
	150	145	129	127	141	147
	200	134	124	131	143	144
		Percent of Portland-Slag Cement (Type I-S) Control				
4.5 Portland-Slag Cement (Type I-S)	75	105	109	109	112	108
	150	89	99	107	112	107
	200	81	92	102	102	104
		Percent of Portland Cement (Type I) Control				
4.5 Portland-Slag Cement (Type I-S)	0	109	106	124	138	143
	75	115	115	135	155	154
	150	97	105	132	155	153
	200	88	97	126	142	148

The portland-slag cement produces a strength effect in concrete similar to that observed when fly ash or other pozzolanic material is added to portland cement. The strength of the concrete made with portland-slag cement is about equal to that made with normal portland cement through the first 7 days, but at later ages gains strength at a much faster rate so that in this case the portland-slag cement control mix had strength 43 percent above that of the normal portland cement control at one year.

There does not appear to be much advantage in the use of fly ash with portland-slag cement on the basis of these compressive strength results. This work has been accomplished with one brand of portland-slag cement. Other investigators have found that fly ash reacts differently with cements of varying chemical composition. No information is presently available to determine whether all brands of portland-slag cement when used with fly ash produce this small amount of pozzolanic strength gain due to the fly ash, or if it is this one brand which does not have the proper chemical composition for an advantageous reaction. With the normal portland cement, three brands were combined to overcome such differences in a single cement.

The compressive strength results are shown graphically in Figs. 1 and 2 for the concrete made with portland cement and portland-slag cement, respectively. Results of comparable mixes from a previous report (2211-12-P) are also shown in Fig. 1. The compressive strength of the two sets of cylinders is in very close agreement through 90 days of age although the mixes were made nearly one year apart. Between 90 days and one year the concrete containing fly ash in the earlier study failed to gain in strength appreciably and consequently are greatly below the strength of comparable concrete made in the later study. The strength gain of the concrete made in the later study is orderly in all cases.


Compressive Strength - psi
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1
3
7
28
90
365
Age – Days
200 lb
150 lb
150 lb
75 lb
No fly ash
Dashed lines indicate strength of comparable mixes in report number 2211-12-P
Legend
x No fly ash
o 75 lb fly ash per cubic yard
Δ 150 lb fly ash per cubic yard
□ 200 lb fly ash per cubic yard
Note
Pounds of fly ash per cubic yard shown on curves.
Each point represents average compressive strength of six 6"x12" laboratory moist-cured test cylinders.
Slump averages 3-1/2" to 4-1/2"
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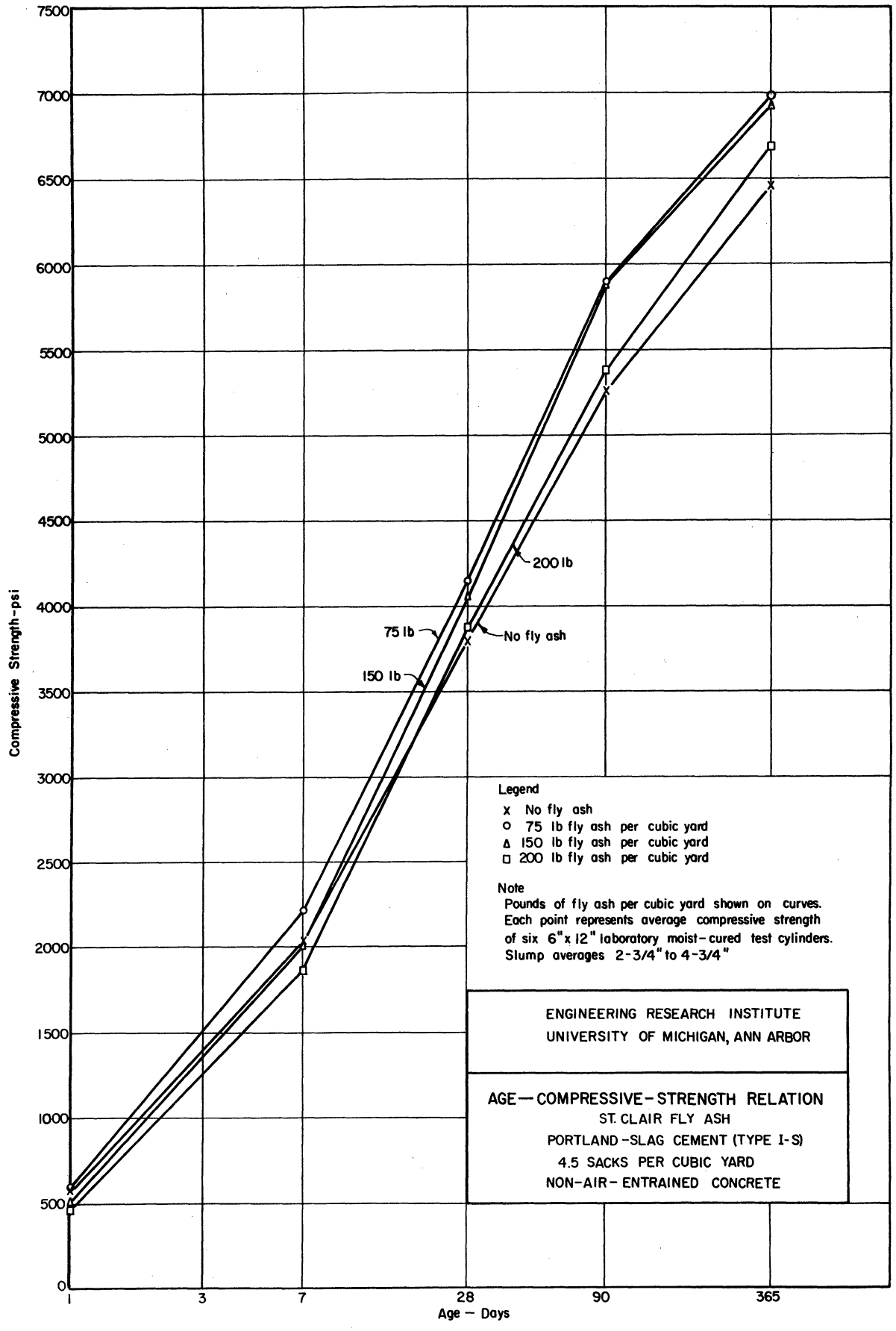
AGE – COMPRESSIVE – STRENGTH RELATION
ST. CLAIR FLY ASH
PORTLAND CEMENT (TYPE I)
4.5 SACKS PER CUBIC YARD
NON-AIR-ENTRAINED CONCRETE

Fig 1


Compressive Strength-psi
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1
3
7
28
90
365
Age — Days
200 lb
75 lb
No fly ash
150 lb
Legend
x No fly ash
o 75 lb fly ash per cubic yard
Δ 150 lb fly ash per cubic yard
□ 200 lb fly ash per cubic yard
Note
Pounds of fly ash per cubic yard shown on curves.
Each point represents average compressive strength of six 6"x 12" laboratory moist-cured test cylinders.
Slump averages 2-3/4" to 4-3/4"
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UNIVERSITY OF MICHIGAN, ANN ARBOR
AGE—COMPRESSIVE-STRENGTH RELATION
ST. CLAIR FLY ASH
PORTLAND-SLAG CEMENT (TYPE I-S)
4.5 SACKS PER CUBIC YARD
NON-AIR-ENTRAINED CONCRETE

Fig 2

APPENDIX

TABLE I-A

PROPERTIES OF PORTLAND CEMENT
56C-108 (Type I)

Physical Properties

Specific surface, air permeability test, sq cm/gm	3116
Autoclave expansion, percent	0.07
Normal consistency, percent	24.8
Time of set, Gilmore	
Initial	4 hr, 5 min
Final	6 hr, 5 min
Compressive strength, psi	
7 days	3263
28 days	4863
Air in mortar, percent	11.3

Chemical Properties		Percent by Weight
Silicon dioxide	SiO_2	21.5
Aluminum oxide	Al_2O_3	5.8
Ferric oxide	Fe_2O_3	3.0
Calcium oxide	CaO	62.8
Magnesium oxide	MgO	2.7
Sulfur trioxide	SO_3	2.0
Loss on ignition		1.7
Sodium oxide	Na_2O	0.12
Potassium oxide	K_2O	0.75
Tricalcium silicate	$3CaO.SiO_2$	43
Dicalcium silicate	$2CaO.SiO_2$	29
Tricalcium aluminate	$3CaO.Al_2O_3$	10
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	9
Total alkali expressed as Na_2O		0.61

TABLE II-A

PROPERTIES OF PORTLAND-SLAG CEMENT
56C-111 (Type I-S)

Physical Properties

Specific surface, air permeability test sq cm/gm	4030
Autoclave expansion, percent	0.02
Normal consistency, percent	27.2
Time of set, Vicat	5 hr, 5 min
Compressive strength, psi	
7 days	3104
28 days	6150
Specific gravity	3.06
Air in mortar, percent	8.7

Chemical Properties		Percent by Weight
Silicon dioxide	SiO_2	28.0
Aluminum oxide	Al_2O_3	8.3
Ferric oxide	Fe_2O_3	2.2
Calcium oxide	CaO	55.0
Magnesium oxide	MgO	3.4
Sulfur trioxide	SO_3	1.7
Loss on ignition		1.2
Sodium oxide	Na_2O	0.10
Potassium oxide	K_2O	0.70
Manganic oxide	Mn_2O_3	0.37
Sulfur	(S)	0.30

TABLE III-A

PROPERTIES OF FLY ASH

Physical Properties	St. Clair Fly Ash	ASTM Requirement C350-54T
Specific surface, air permeability test, sq cm/gm	3012	2800 min
Compressive strength, 20% by weight of portland cement addition, hand mixing, 73°F cure, percent of control		
7 days	114	
28 days	119	
90 days	129	
Water requirement, percent of control	112	
Compressive strength, 25% by weight of sand, sand replacement, machine mixing, 73°F cure, percent of control		
7 days	162	
28 days	167	
90 days	204	
Water requirement, percent of control	115	
Compressive strength, 25% by weight of cement, sand replacement, machine mixing, 73°F cure, percent of control		
7 days	148	100 min
28 days	143	100 min
90 days	150	
Water requirement, percent of control	100	
Drying shrinkage, 28 days, percent	0.08	0.10 max
Soundness, autoclave expansion, percent	0.06	0.50 max
Specific gravity	2.47	

TABLE III-A (Cont.)

PROPERTIES OF FLY ASH

Chemical Properties	Percent by Weight, Moisture-Free Basis	
	St. Clair Fly Ash	ASTM Requirement C350-54T
Silicon dioxide, SiO_2	36.9	40.0 min
Magnesium oxide, MgO	1.3	3.0 max
Sulfur trioxide, SO_3	0.9	3.0 max
Loss on ignition	8.6	12.0 max
Moisture	0.3	3.0 max

TABLE IV-A

4.5 SACKS PORTLAND CEMENT (TYPE I) PER CUBIC YARD REGULAR CONCRETE — ST. CLAIR FLY ASH

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content, sk/cu yd	V_s**	Material Proportions lb/cu yd Sand	Stone	Net Water	W/C, gal/sk	Weight or Fresh Concrete, lb/cu ft	Slump, in.	Compressive Strength, psi 1 Day	7 Days	28 Days	90 Days	1 Year
345	3-5-56	0	4.40	0.64	1523	1815	277	7.39	148.1	2	500	1835	3090	3745	4645
											475	1855	2970	3605	4505
360	3-19-56	0	4.47	0.64	1491	1815	270	7.20	148.9	2.5	570	2140	3305	4525	4840
											550	2065	3745*	4240	5460*
368	3-26-56	0	4.46	0.64	1500	1815	257	6.85	148.4	7	610*	1855	2895	3250	4115
											500	1800	2510*	3465	4505
	Average	0	4.44	0.64	1505	1815	268	7.15	148.5	3.8	519	1925	3065	3805	4522
346	3-5-56	75	4.35	0.72	1250	2041	255	6.81	146.4	3.75	610	2280	3885	5140	5425*
											630	2420	3870	5140	6325
353	3-12-56	75	4.50	0.72	1236	2041	245	6.54	150.8	3	820	2490	1945*	5125	6185
											800	2490	3835	5090	6645
361	3-19-56	75	4.48	0.72	1236	2041	252	6.73	150.4	4	665	2510	3780	5300	6325
											680	2420	3850	5300	6450
	Average	75	4.44	0.72	1241	2041	251	6.69	149.2	3.6	701	2435	3844	5183	6386
354	3-12-56	150	4.50	0.78	977	2212	256	6.83	150.5	5.75	660	2330	3640	5335	6485
											650	2120	3425	5035	6465
362	3-19-56	150	4.47	0.78	1000	2212	252	6.73	150.4	4.5	655	2440	4030	5655	6465
											670	2580	4205	5335	6855
369	3-26-56	150	4.48	0.78	1000	2212	245	6.52	150.3	3.5	920	2720	4205	5510	6645
											960	2705	3850	5405	6995
	Average	150	4.48	0.78	992	2212	251	6.69	150.4	4.6	753	2483	3893	5379	6652
355	3-12-56	200	4.48	0.81	835	2296	267	7.13	150.0	3.5	585	2245	3920	5335	6395
											595	2350	3850	5335	6450
363	3-19-56	200	4.50	0.81	825	2296	262	6.99	150.1	4	670	2295	4135	5830	6305
											660	2525	3445*	5620	6625
370	3-26-56	200	4.47	0.81	835	2296	250	6.68	149.0	4.5	840	2490	3995	5335	6570
											835	2405	4150	5160	6855
	Average	200	4.48	0.81	832	2296	260	6.93	149.7	4.0	698	2385	4010	5436	6533

*Not included in average.

**Denotes volume of dry-rodded coarse aggregate per unit volume of concrete.

TABLE IV-A

4.5 SACKS PORTLAND CEMENT (TYPE I) PER CUBIC YARD REGULAR CONCRETE — ST. CLAIR FLY ASH

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content, sk/cu yd	V_s**	Material Proportions lb/cu yd			W/C, gal/sk	Weight or Fresh Concrete, lb/cu ft	Slump, in.	Compressive Strength, psi				
					Sand	Stone	Net Water				1 Day	7 Days	28 Days	90 Days	1 Year
345	3-5-56	0	4.40	0.64	1523	1815	277	7.39	148.1	2	500	1835	3090	3745	4645
											475	1855	2970	3605	4505
360	3-19-56	0	4.47	0.64	1491	1815	270	7.20	148.9	2.5	570	2140	3305	4525	4840
											550	2065	3745*	4240	5460*
368	3-26-56	0	4.46	0.64	1500	1815	257	6.85	148.4	7	610*	1855	2895	3250	4115
											500	1800	2510*	3465	4505
	Average	0	4.44	0.64	1505	1815	268	7.15	148.5	3.8	519	1925	3065	3805	4522
346	3-5-56	75	4.35	0.72	1250	2041	255	6.81	146.4	3.75	610	2280	3885	5140	5425*
											630	2420	3870	5140	6325
353	3-12-56	75	4.50	0.72	1236	2041	245	6.54	150.8	3	820	2490	1945*	5125	6185
											800	2490	3835	5090	6645
361	3-19-56	75	4.48	0.72	1236	2041	252	6.73	150.4	4	665	2510	3780	5300	6325
											680	2420	3850	5300	6450
	Average	75	4.44	0.72	1241	2041	251	6.69	149.2	3.6	701	2435	3844	5183	6386
354	3-12-56	150	4.50	0.78	977	2212	256	6.83	150.5	5.75	660	2330	3640	5335	6485
											650	2120	3425	5035	6465
362	3-19-56	150	4.47	0.78	1000	2212	252	6.73	150.4	4.5	655	2440	4030	5655	6465
											670	2580	4205	5335	6855
369	3-26-56	150	4.48	0.78	1000	2212	245	6.52	150.3	3.5	920	2720	4205	5510	6645
											960	2705	3850	5405	6995
	Average	150	4.48	0.78	992	2212	251	6.69	150.4	4.6	753	2483	3893	5379	6652
355	3-12-56	200	4.48	0.81	835	2296	267	7.13	150.0	3.5	585	2245	3920	5335	6395
											595	2350	3850	5335	6450
363	3-19-56	200	4.50	0.81	825	2296	262	6.99	150.1	4	670	2295	4135	5830	6305
											660	2525	3445*	5620	6625
370	3-26-56	200	4.47	0.81	835	2296	250	6.68	149.0	4.5	840	2490	3995	5335	6570
											835	2405	4150	5160	6855
	Average	200	4.48	0.81	832	2296	260	6.93	149.7	4.0	698	2385	4010	5436	6533

*Not included in average.
**Denotes volume of dry-rodded coarse aggregate per unit volume of concrete.

TABLE V-A

4.5 SACKS PORTLAND-SLAG CEMENT (TYPE I-S) PER CUBIC YARD REGULAR CONCRETE — ST. CLAIR FLY ASH

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content, sk/cu yd	V_s**	Material Proportions lb/cu yd			W/C, gal/sk	Weight of Fresh Concrete, lb/cu ft	Slump, in.	Compressive Strength, psi				
					Sand	Stone	Net Water				1 Day	7 Days	28 Days	90 Days	1 Year
348	3-7-56	0	4.51	0.64	1513	1815	245	6.55	150.0	3.5	645	2100	4205	5705	6590
											650	2175	3850	6040	6535
356	3-14-56	0	4.42	0.64	1548	1815	251	6.69	148.5	2.5	525	1945	3445	4770	6060
											505	2085	3850	4770	6445
364	3-21-56	0	4.40	0.64	1548	1815	255	6.81	148.3	2.5	525	1960	3570	5160	6450
											560	1945	3870	5160	6610
	Average	0	4.44	0.64	1536	1815	250	6.68	148.9	2.8	568	2035	3798	5268	6448
349	3-7-56	75	4.45	0.72	1240	2041	244	6.52	149.2	5	705	2525	4540	6450	7140
											665	2280	4715	6150	7720
357	3-14-56	75	4.46	0.72	1266	2041	246	6.56	150.4	3.5	550	2120	3730	5760	6395
											550	2120	3570	5230	6415
365	3-21-56	75	4.44	0.72	1256	2041	249	6.65	149.6	4.75	550	2120	4365	5920	6980
											570	2120	3995	5900	7190
	Average	75	4.45	0.72	1254	2041	246	6.58	149.7	4.4	598	2214	4153	5902	6973
350	3-7-56	150	4.49	0.78	966	2212	249	6.64	149.7	2.5	515	1980	4295	6345	6960
											535	2050	4045	6115	6980
358	3-14-56	150	4.43	0.78	980	2212	268	7.15	148.8	3.75	450	1960	3920	5740	6835
											485	2030	4045	5300	6680
366	3-21-56	150	4.49	0.78	971	2212	256	6.83	150.0	4.75	535	2065	4240	4945*	6660
											510	1995	3800	5920	7405
	Average	150	4.47	0.78	972	2212	258	6.87	149.5	3.7	505	2013	4058	5884	6920
351	3-7-56	200	4.50	0.81	784	2296	269	7.18	148.7	5	445	1800	3960	5300	6590
											450	1820	3765	5740	6360
359	3-14-56	200	4.46	0.81	825	2296	272	7.25	149.0	4.5	435	1855	3835	4860	6430
											460	1890	2630*	5475	6380
367	3-21-56	200	4.45	0.81	825	2296	270	7.20	148.8	5	490	1945	3920	5370	7030
											475	1875	3885	5565	7330
	Average	200	4.47	0.81	811	2296	270	7.21	148.8	4.8	459	1864	3873	5385	6687

*Not included in average.

**Denotes volume of dry-rodded coarse aggregate per unit volume of concrete.