Stabilization of Soils with Fly Ash Alone

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Fly ash reacts with lime to form a cementing material used to strengthen soils for the construction of bases and subbases for pavements. To sustain the cementitious reaction, lime must be added or supplied to the fly ash. Nevertheless, a survey of fly ashes revealed that some of them contain cementing materials—lime or other products—in a quantity sufficient for good strength. The stabilization of soils with fly ashes that do not need added lime should be a very competitive method when the transportation cost of the fly ash is within economical limits. This paper presents the results obtained with several fly ashes used without lime to stabilize several soils with different textures.

•SOIL STABILIZATION, a relatively new science, aims at the improvement of the engineering characteristics of soils, either by physical means or by treating the soils with different products. Some of the successful stabilizing agents are cement, lime, and lime plus fly ash. Fly ash, an artificial pozzolan, reacts with lime to produce strength through cementation (1).

The stabilization of soils with lime and fly ash is a well-known process used in the construction of pavements for roads, airfields and parking lots. The advantages of this method of soil stabilization stem from the fact that fly ash is a waste product of power plants and is available at a low price. However, from 2 to 9 percent lime is added, bringing this method to a cost comparable to that of other methods of soil stabilization.

Although the general understanding is that fly ash reacts only with lime, exploratory studies showed that some fly ashes produce strength without the addition of lime (2). Extensive studies made with two cementitious fly ashes in the stabilization of several soil materials are presented in this investigation.

MATERIALS

Fly Ashes

Preliminary studies were made using several fly ashes selected from a group of 21 fly ashes extensively studied by the author (3, 4, 5). Five fly ashes were found to produce an adequate cementation of a sandy soil, and two of these fly ashes gave such high strengths that they were further evaluated with a variety of soil materials. The analyses of the five fly ashes are given in Table 1.

Fly Ash A. —This sample was collected by mechanical precipitators (cyclone type). The coal was from Missouri and was pulverized and burned in suspension in Combustion Engineering boilers. The sample was from Montrose Station Power Plant of the Kansas City, Mo., Power and Light Company.

Fly Ash B. —This sample was collected by mechanical precipitators (multicone dust collectors). The coal was from Iowa, unwashed, pulverized and tangential fired. The sample was from the Des Moines Power Plant of the Iowa Power and Light Company.

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TABLE 1

ANALYSIS OF FLY ASHES

Fly Ash Designation	Analysis (%)							Passing No. 325 Sieve (%)	Spec. Grav. (g/cm³)	Spec. Surf. (cm²/g)
	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	C			
A	39.2	30.2	11.9	11.6	0.8	1.9	2.8	57.4	2.33	1,730
B	40.1	36.6	13.1	5.8	0.3	2.4	0.2	31.8	2.82	1,460
C	35.3	43.4	7.8	5.3	0.9	1.4	3.8	64.8	2.69	2,048
D	40.5	20.8	12.4	10.6	0.3	2.0	7.8	57.6	2.44	2,109
E	51.2	20.2	10.0	6.3	1.6	1.7	1.0	80.7	2.34	2,539

TABLE 2

ANALYSES OF SOILS

Soil	Passing Sieve (%)[a]						Liquid Limit (%)	Plasticity Index
	¾ in.	No. 4	No. 10	No. 40	No. 100	No. 200		
Sonon limestone	100	32	15	6	4	3	-	NP
Rapid limestone	100	30	17	8	7	6	-	NP
Limestone screenings	100	98	68	48	29	19	-	NP
Bottom furnace ash	100	100	65	18	7	3	-	NP
Dune sand	100	100	100	ND	ND	4	-	NP
Colfax sand-loess mix	100	100	100	ND	ND	29	19	3
Friable loess	100	100	100	100	99	98	32	7
Gumbotil	100	100	100	97	93	81	76	50

[a]ND = Not determined.

TABLE 3

COMPRESSIVE STRENGTH RESULTS OF DUNE SAND-FLY ASH MIXTURES[a]

Fly Ash	Curing Period (days)	Compressive Strength (psi)			
		80:20[b]	73:27[b]	65:35[b]	100:0[b]
A	7	102	138	172	310
	28	193	273	378	746
	90	288	440	606	982
B	7	46	51	51	150
	28	138	217	288	665
	90	272	452	593	1,110
C	7	26	41	43	ND
	28	43	89	145	392
	90	74	175	298	702
D	7	60	69	74	ND
	28	110	152	192	276
	90	244	267	350	475
E	7	33	66	95	ND
	28	43	101	167	196
	90	51	138	201	238

[a]Cured at 71 F. [b]Sand to fly ash.

Fly Ash C. —This sample was collected by mechanical precipitators (cyclone type). The coal was from Missouri and Kansas mines. The coal was pulverized and burned in suspension in Combustion Engineering boilers. The sample was sent from the Hawthorne Station Power Plant of the Kansas City, Mo., Power and Light Company.

Fly Ash D. —This sample was sent by the Kansas City, Mo., Power and Light Company. No data are available on the source.

Fly Ash E. —This sample was collected by electrical precipitators. The coal was from southern Illinois and was crushed in a bowl crusher. The sample was from the Meramec Station Power Plant of the Union Electric Company of Saint Louis, Mo.

Soils

Eight different kinds of soil materials and aggregates were selected to represent a wide variety in physical and chemical characteristics; their analyses are given in Table 2.

PROCEDURES

The soils were air dried and the soil aggregations broken down by grinding. The dried soils were mixed with the dry fly ash in a laboratory mixer for 0.5 min. Test specimens of the two crushed limestone soils, 4 in. in diameter by 4.6 in. in height were molded according to ASTM Specification D 558-57 (6). Test specimens of the other six soils, 2 in. in diameter by 2 in. in height, were molded with the Iowa State Compaction Apparatus (1, 2, 3, 4, 7) to a maximum density close to that of the other samples. Specimens were molded at several moisture contents.

After molding, the specimens were wrapped in waxed paper, sealed with cellophane tape, and stored for curing in a moist room at 71 ± 3 F and greater than 90 percent RH. The specimens were cured for 7, 28 and 90 days, followed by immersion in water for 1 day. They were then tested under unconfined compression to determine their maximum water stable strength.

RESULTS

Part of the preliminary studies made using fly ashes and a dune sand soil are presented in Table 3. The results indicate that some fly ashes alone can cement soil particles. Two of the five fly ashes (A and B) gave such high strengths that they could be used with the dune sand in the construction of base and subbase courses for pavements.

These two fly ashes were further evaluated with more soils (Figs. 1 to 4). Strengths of 400 psi or more were obtained after 28 days curing with six of the soils. The only two soils that gave 28-day strengths lower than 400 psi were the friable loess and the gumbotil (Fig. 4). However, these soils are not satisfactory, stabilized even with fly ash plus added lime (1, 5).

In recent studies with soil-cement mixtures (8), it has been found that a 7-day laboratory unconfined compressive strength of 453 ± 22 psi is adequate for a base course. If it is assumed that the same strength requirements are valid for soil and

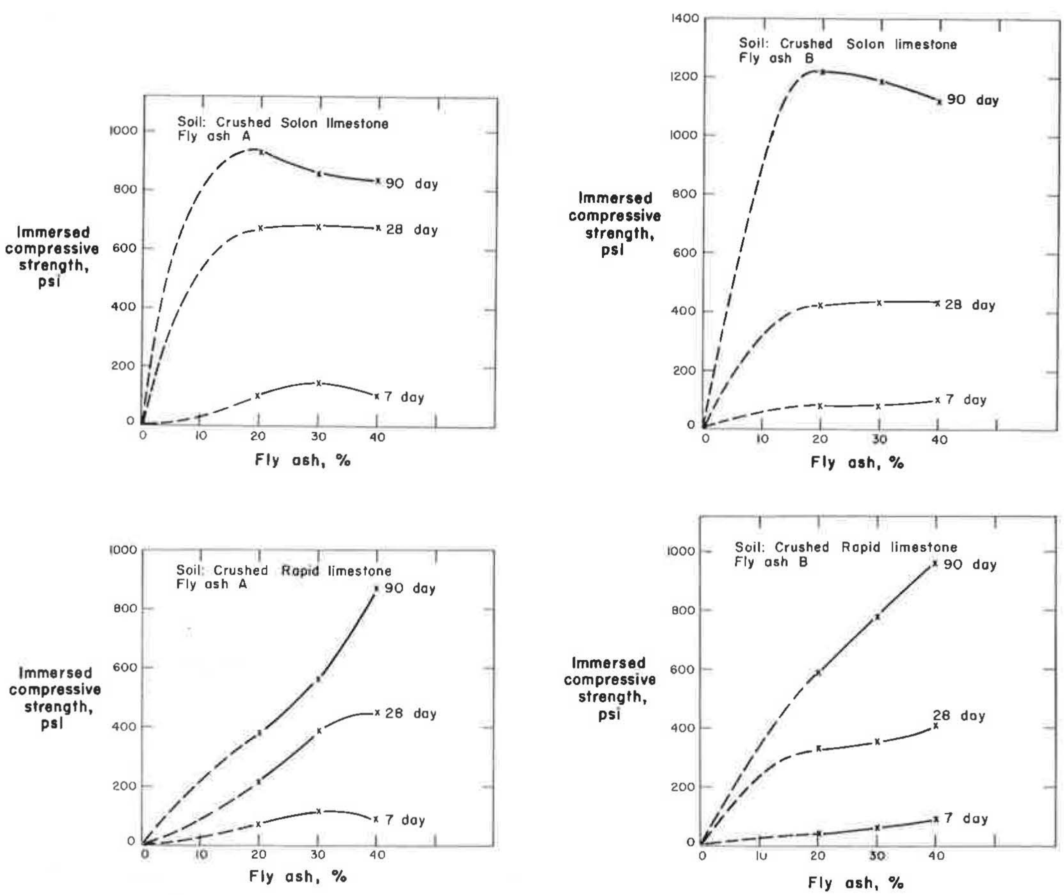

Figure 1. Immersed unconfined compressive strength of soil-fly ash mixtures moist cured for 7, 28 and 90 days.

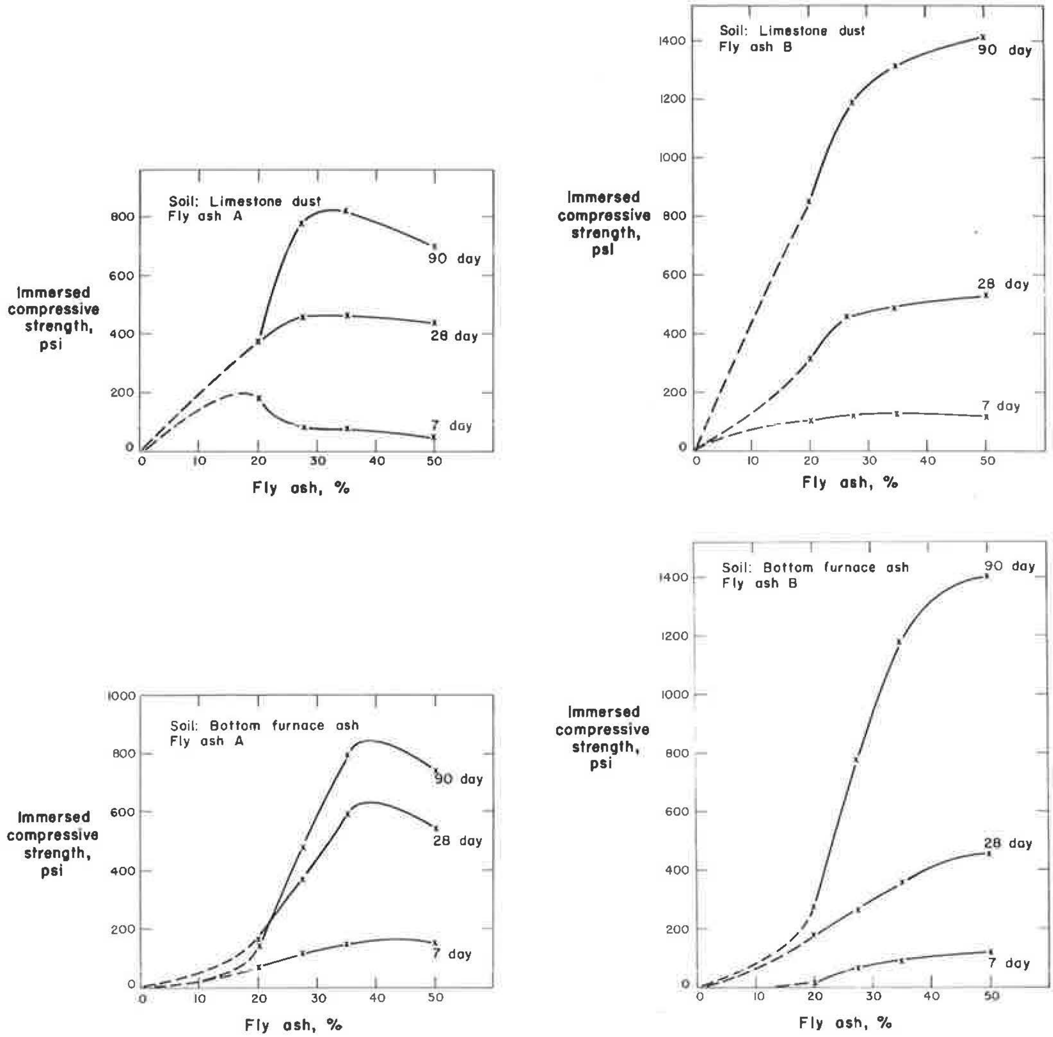

Figure 2. Immersed unconfined compressive strength of soil-fly ash mixtures moist cured for 7, 28 and 90 days.

fly ash mixtures cured for 28 days, fly ashes A and B can be used with six of the soils in the construction of base courses for pavements.

It should be emphasized that the strength of most of the soils treated continued to increase after 28 days, reaching strengths of 1,000 psi or more after 90 days of curing. The 7-day strengths are very low, usually about 100 psi, but this is true also for soils stabilized with lime plus fly ash (1, 5).

MECHANISM

Fly ash is a by-product of the power plants burning powdered coal. The suspended noncombustibles during the burning process are subjected to very high temperatures, such that individual mineral grains melt to form individual grains of fly ash. Possibly marly materials in the fly ash suffer changes in structure during the burning process similar to those in the formation of portland cement clinker, although this is highly speculative and has not been verified by X-ray analysis. Fly ash can thus be a kind

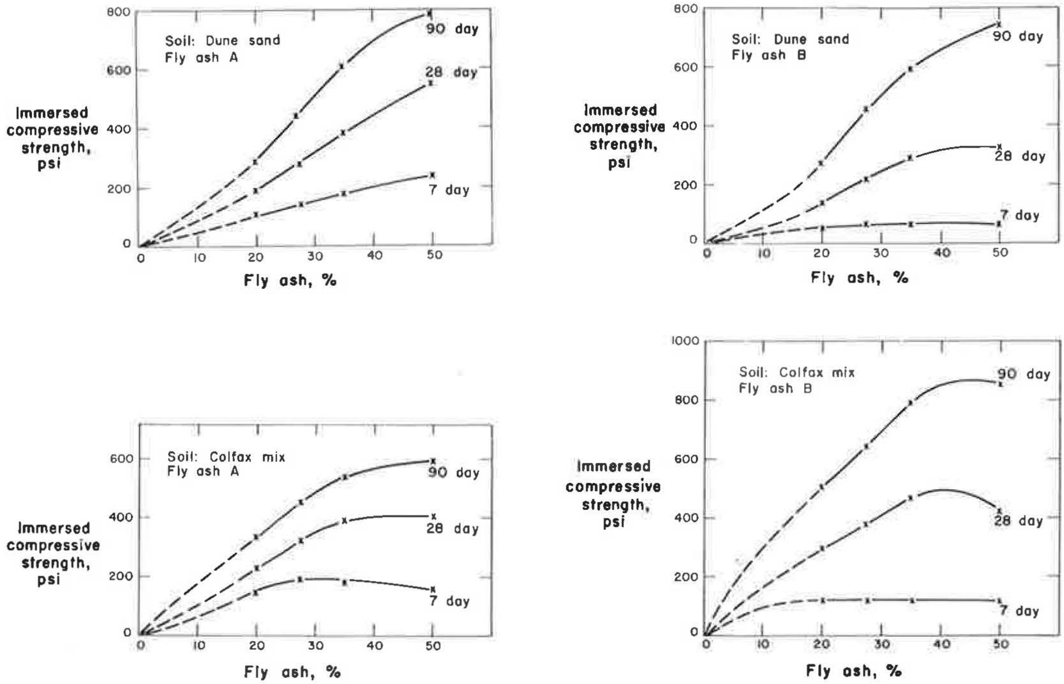

Figure 3. Immersed unconfined compressive strength of soil-fly ash mixtures moist cured for 7, 28 and 90 days.

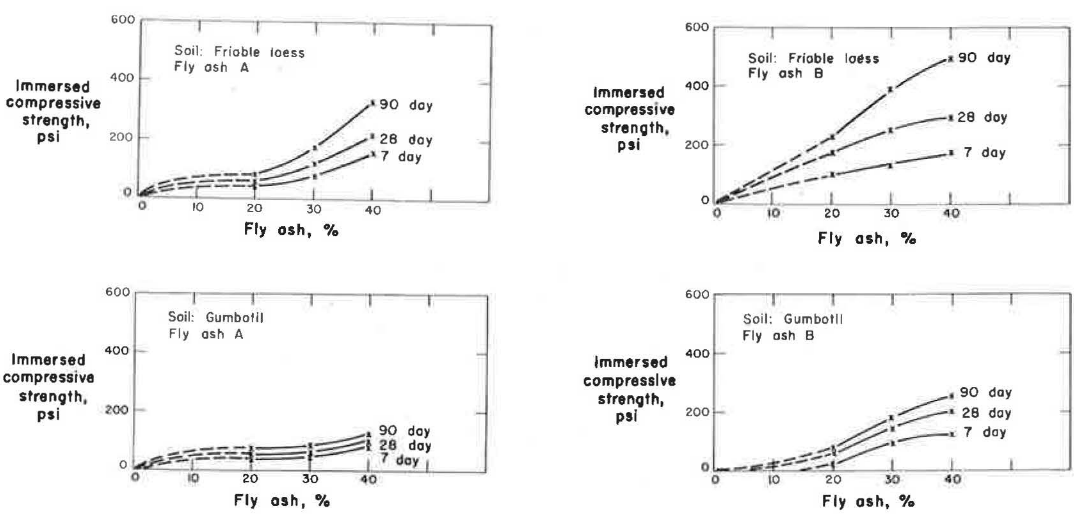

Figure 4. Immersed unconfined compressive strength of soil-fly ash mixtures moist cured for 7, 28 and 90 days.

of cement similar to ground clinker. Because the fly ash is minute, the particles may not require grinding to act with water as a cementing agent.

Free lime may already be present in the reactive fly ashes, so that none must be added for the lime-fly ash reaction to occur. Small amounts of free lime were found by chemical analysis (Table 1), and $Ca(OH)_2$ has been found in X-ray traces.

TABLE 4

COMPRESSIVE STRENGTH RESULTS OF SPECIMENS OF FLY ASH[a]

Fly Ash	Compressive Strength (psi)	
	1 Day	3 Days
A	878	923
B	687	827
C	445	570
D	205	242
E	167	220

[a]Curing period under steam at 248 F and 1 atm pressure.

SELECTION OF FLY ASHES

The choice of a fly ash to be used in concrete or in mixtures with lime is difficult because the strength and other requirements of fly ash are difficult to predict from physical or chemical characteristics (3). The ASTM has set standards for selecting a fly ash for such uses, but these standards need revision (3, 4).

A fly ash to be used alone in the stabilization of a soil should be carefully chosen. The best way to determine the suitability of a fly ash is to mold specimens under different moisture contents for several soil and fly ash combinations and cure them under standard conditions, up to 90 days. Selection can be made more simply by a quick test using steam to cure the specimens (4, 9). Specimens of fly ash for this quick test are prepared in the Iowa State Compaction Apparatus, giving five blows to each side of the specimen with the 5-lb hammer. The specimens are then wrapped in polyvinylidene chloride and sealed with cellophane tape. The specimens are preheated for about 2 hr in a 140 F oven and then autoclaved at 248 F and 1 atm pressure. The specimens are preheated to make the increase in temperature more gradual. After 24 hr of curing, the specimens are removed from the autoclave and placed in distilled water for 2 hr. They are then tested for unconfined compressive strength. Those fly ashes giving a strength of 600 psi or more may be considered good cementing materials for stabilizing soils for base and subbase courses of pavements (Table 4). The fly ashes with more than 600 psi under the quick test should be further evaluated with the actual soils to be used.

Another correlation found is that those fly ashes showing greatest strengths without added lime are more alkaline than others (2). The alkalies may make the fly ashes as reactive without lime as mixtures with lime (10, 11, 12). Until more information is obtained, the quick test should be used for the preliminary selection of a cementitious fly ash.

CONCLUSIONS

1. Some fly ashes possess cementitious qualities in themselves without addition of lime.

2. Some fly ashes can be used to stabilize soils. The soils that respond best are nonplastic coarse-grained soils, such as gravel, sand and slag. Strengths of 400 psi or more can be reached after 28-days curing with some combinations of soil and fly ash. These combinations are sufficient in strength to be used for the base courses of pavements.

ACKNOWLEDGMENT

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