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EFFECT OF CEMENT-FLY ASH-KILN DUST ON STRENGTH OF MORTAR

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ABSTRACT

In this study, experiments were conducted to investigate the influence of selected parameters on the compressive strength and performance of cement-fly ash-kiln dust mortar. The percentage of cement was varied from 20% to 80% by weight of cementitious (cement+fly ash+kiln dust) materials. The results show that fly ash-kiln dust mortars with higher cement content give higher compressive strengths than those with lower cement contents. For mixes with a constant amount of cement, the proportion of fly ash and kiln dust has to be adjusted to achieve the optimum compressive strength. At 28 days, the compressive strengths of cement-fly ash-kiln dust mortars with cement content of 20%, 40%, 60%, and 80% of cementitious materials were 37%, 51%, 70%, and 89%, respectively, when compared with conventional cement mortar. These strengths increase to 53%, 76%, 88%, and 95%, respectively as the age of mortars increase to 180 days.

INTRODUCTION

Fly ash, which is a by-product of coal burning thermal power plants, is produced in large quantities each year. While potential uses for this product are available, most fly ash ends up in landfills, skyrocketing disposal costs and creating potential environmental hazards. Many investigators are searching for ways to utilize this by-product, rather than disposing it in the landfill. Kiln dust, as the name implies, is a waste product of cement manufacturing collected from gases emanating from the rotary kiln. It has some cementitious properties since the main constituent of kiln dust is calcium oxide (CaO). The cementitious and pozzolanic qualities of kiln dust and fly ash can be enhanced when in the combination of each other. This reaction can be understood by analyzing their chemical compositions. Kiln dust, which is rich in calcium oxide (CaO), contributes calcium while fly ash provides silica and alumina to produce calcium silicate hydrate [C-S-H] gel. This combination is believed to increase the calcium silicate hydrate content of low calcium fly ash (Class F) mortars. Ramakrishnan (1) studied the use of cement blended with kiln dust versus the properties of concretes made with plain portland cement. The blending of 5% kiln dust with 95% of cement provided a compound which prolonged the setting time of blended cement and concrete. The concrete made with blended cement behaves almost the same as those of plain concrete.

Large volumes of fly ash have potential application as structural fills, highway base material and fill. Such fill is normally a mixture of kiln dust or lime, fly ash, and aggregate such as sand. The mixture for each application must be designed to have adequate strength, easy placement and compaction, and be economical. In certain soil conditions such as saturated sandy silts and silty clays which are marginally reactive with lime or in soils with large void ratios, lime/fly ash slurry mixtures have been successfully used to increase strength and shut off subsurface flows of water and leachates (2). The largest single project involving the combined use of lime, portland cement and fly ash in a base or subbase application was the construction, during the 1970's, of runways, taxiways and aprons during the expansion of the Newark Airport. Field tests showed that stabilized layered mixtures of hydrated lime, portland cement, fly ash, dredged sand, and crushed stone provided a suitable base for the new pavements (3).

EXPERIMENTAL PROGRAM

In this experiment, fly ash was mixed with cement, kiln dust, river sand, and water. Sand, cementitious materials (cement+fly ash+kiln dust), and water were kept constant while the percentages of cement and fly ash were varied from 20% to 80% by weight of cementitious materials. Table 1 shows the chemical composition of fly ash, kiln dust, and cement used in this study. The mix proportions of cement-fly ash-kiln dust mortar are shown in Table 2. All samples were cured in saturated lime water until the day of testing. The compressive strengths of 2"x2"x2" cubes of these mixes were tested at the age of 1, 3, 7, 14, 28, 56, 90, and 180 days. Setting times of cement and the combination of cement-fly ash-kiln dust paste were tested using both the Vicat and Gillmore methods.

Table 1 Chemical Composition of Fly Ash, Kiln Dust, and Cement

Constituent	Fly Ash	Kiln Dust	Cement
SiO_2	53.57	12.29	19.96
Al_2O_3	26.70	7.07	8.92
CaO	1.65	43.23	59.33
Fe_2O_3	5.08	3.32	2.72
MgO	0.77	2.73	3.10
Na_2O	0.30	0.39	0.43
K_2O	1.99	2.59	0.88
SO_3	0.70	5.56	2.76

Table 2 Mix Proportion

Sample	Cementitious Materials (M)			Sand/M Ratio	Water/M Ratio
	Portland Cement (%)	Fly Ash (%)	Kiln Dust (%)		
EKO	100	-	-	2.75	0.5
AK000	20	0	80	2.75	0.5
AKD20	20	20	60	2.75	0.5
AKD40	20	40	40	2.75	0.5
AKD60	20	60	20	2.75	0.5
AKD80	20	80	0	2.75	0.5
BK000	40	0	60	2.75	0.5
BKD20	40	20	40	2.75	0.5
BKD40	40	40	20	2.75	0.5
BKD60	40	60	0	2.75	0.5
CK000	60	0	40	2.75	0.5
CKD20	60	20	20	2.75	0.5
CKD40	60	40	0	2.75	0.5
DK000	80	0	20	2.75	0.5
DKD20	80	20	0	2.75	0.5

RESULTS AND DISCUSSIONS

Compressive Strength of Cement-Fly Ash-Kiln Dust Mortar

Table 3 shows the compressive strength of cement-fly ash-kiln dust mortar at specified ages. Sample EKO is the control sample, consists only of cement and without any kiln dust or fly ash. Series AK, BK, CK, and DK represent the cement-fly ash-kiln dust mortars with cement content of 20%, 40%, 60%, and 80% of the cementitious materials, respectively. The numbers in each series indicate the portion of fly ash in the cementitious materials.

For Mortar with 20% Cement Content (Series AK)

For this series, the weight of cement is kept constant at 20% of the total cementitious materials. The effect of fly ash-kiln dust on the strength of mortar with cement constant at 20% is shown in Fig. 1. It can be seen that in most cases the mortar strength increases with age with the exception of AK000 (kiln dust 80%, no fly ash) which loses strength after 90 days. This may be due to the instability of the specimen in the saturated lime water environment and it should be noted that the compressive strength of AK000 at 180 days is only 597 psi (4.1 MPa). The compressive strength of AKD40 is about 8% at 1 day and increases to 52% at 180 days when compared to the standard mix of EKO (cement 100%, no fly ash and kiln dust). With the replacement of fly ash and kiln dust up to 80%, the compressive strength of fly ash-kiln dust mortar is about 10% to 20% of the control strength at 7 days. As the age increases, a suitable combination of fly ash and kiln dust increases the compressive strength. For example, the use of 40% fly ash with 40% kiln dust and 20% cement provides mortar (AKD40) which gives a compressive strength of 4196 psi (28.9 MPa) or 52% of the control strength at 180 days.

Table 3 Compressive Strength of Cement-Fly Ash-Kiln Dust Mortar

Sam.	Compressive Strength (psi)							
	1-d	3-d	7-d	14-d	28-d	56-d	90-d	180-d
EK0	2177	4048	4748	5500	6280	7001	7448	8034
AK000	213	342	447	551	668	888	860	597
AKD20	186	304	473	917	1788	2540	2708	2875
AKD40	168	383	938	1590	2290	2907	3552	4196
AKD60	138	569	923	1463	2027	2406	2836	3265
AKD80	180	450	595	713	1035	1466	1548	1768
BK000	559	1042	1288	1858	2942	2988	3200	3408
BKD20	384	1547	2043	2521	3264	3721	4477	5888
BKD40	391	1504	1788	2371	3178	3834	4970	6110
BKD60	468	1060	1449	1768	2571	3022	4179	5461
CK000	1605	3090	3540	3890	4245	5058	5519	5981
CKD20	1553	2751	3327	3628	4038	5341	6080	6834
CKD40	1204	2295	2818	3610	4415	4975	6087	7078
DK000	1977	3936	4474	5272	5726	6123	6430	7145
DKD20	1700	3655	4366	4852	5583	6127	6642	7666

For Mortar with 40% Cement Content (Series BK)

Fig. 2 shows that the strengths of all specimens in this series are lower than the control mix. The strength at 180 days of BK000, which consists of kiln dust 60%, no fly ash, is much lower than the other specimens with the same cement content. The compressive strength of BKD40 (with kiln dust 20% and fly ash 40%) increases from 18% at 1 day to 76.1% at 180 days as compared with the control strength. At the same age, the samples from series BKD give higher strength than the samples from series AKD. This is due to the higher percentage of cement content in series BKD (40% of cement) than in series AKD (20% of cement). The highest strength in series BKD is sample BKD40 which is 6110 psi (42.1 MPa).

For Mortar with 60% Cement Content (Series CK)

Fig. 3 displays the effect of fly ash-kiln dust on the strength of mortar with cement content of 60%. At the early ages of 1 to 14 days, the higher the percentage of kiln dust in the mix, the higher is the compressive strength. After 90 days, the strength of sample CKD40 (no kiln dust, fly ash 40%) is higher than CKD00 and CKD20 samples. This generally implies that kiln dust, which consists of high CaO content, contributes more strength at early ages than fly ash. When the age of the samples increases, the pozzolanic reaction of fly ash becomes dominant and produces higher compressive strength than mixes with higher content of kiln dust. The compressive strength of sample CKD40 varies from 1204 psi (8.3 MPa) at 1 day to 7078 psi (48.8 MPa) at 180 days or 55.3% to 88.1% of the control strength, respectively.

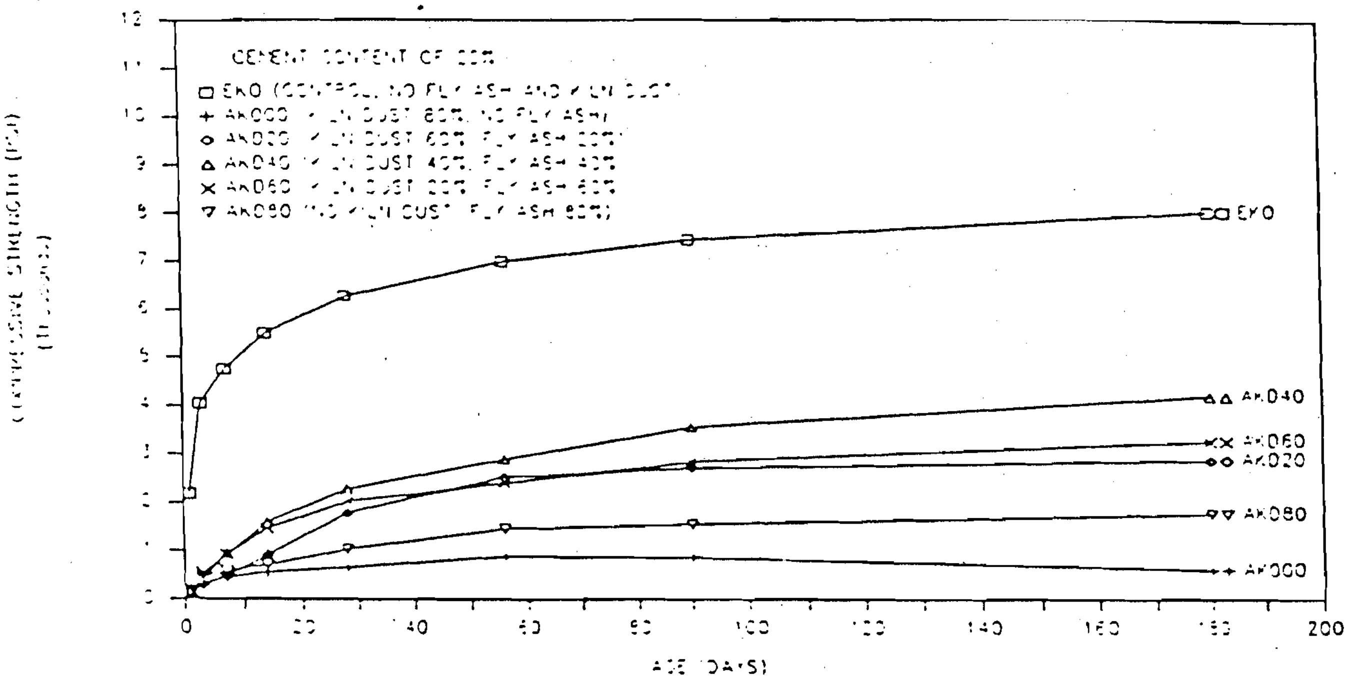

Fig. 1 Effect of Fly Ash-Kiln Dust on the Strength of Mortar with Cement Content of 20%

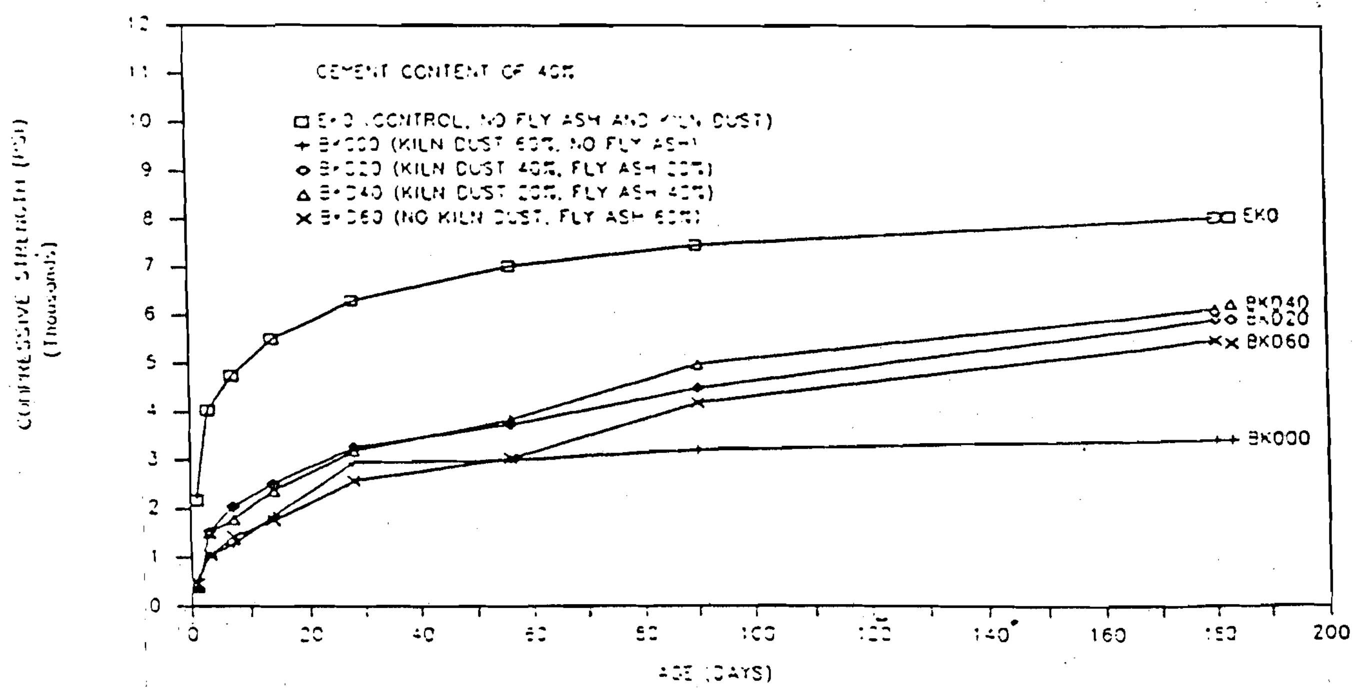

Fig. 2 Effect of Fly Ash-Kiln Dust on the Strength of Mortar with Cement Content of 40%

For Mortar with 80% Cement Content (Series DK)

The effect of fly ash-kiln dust on the strength of mortar with cement content of 80% is shown in Fig. 4. At early ages, the specimen DKD000 (cement 80% and kiln dust 20%) gives higher strength than the specimen DKD20 (cement 80% and fly ash 20%). After 56 days, sample DKD20 gives higher strength than DKD000. This effect is similar to those observed from series CKD discussed previously. The compressive strengths of samples DKD20 and DKD00 at 180 days are 7666 psi (52.8 MPa) and 7145 psi (49.3 MPa), or 95.4% and 88.9% of the control strength, respectively.

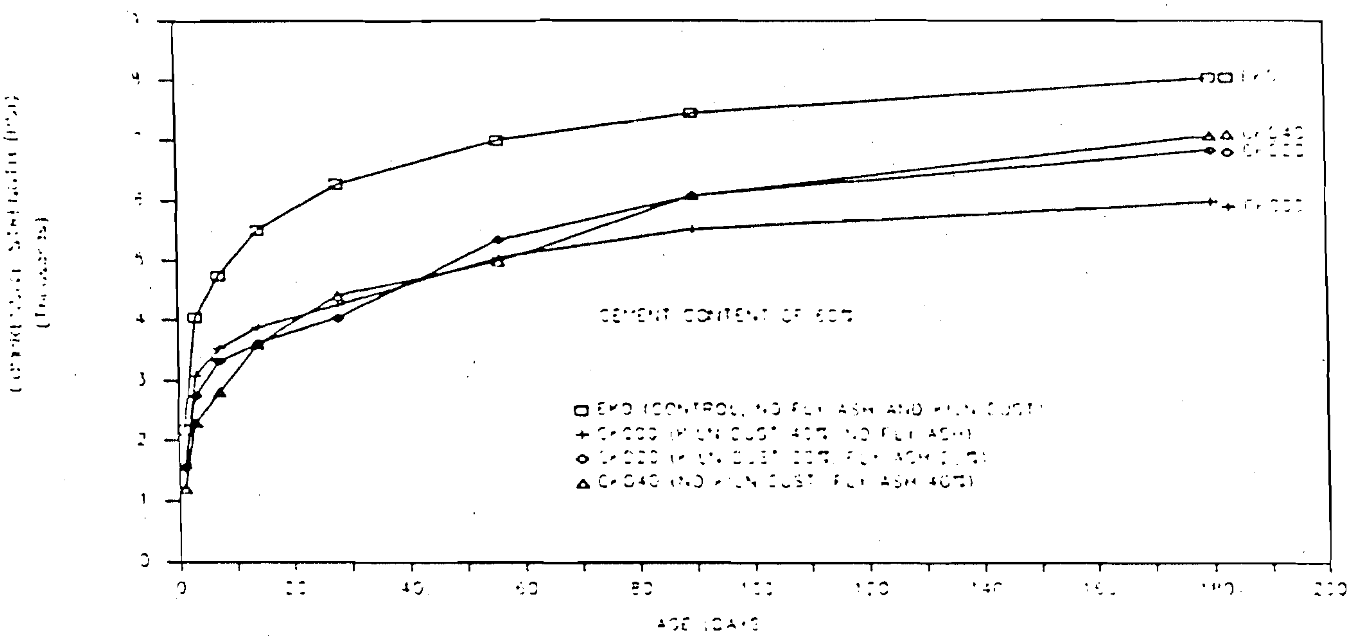

Fig. 3 Effect of Fly Ash-Kiln Dust on the Strength of Mortar with Cement Content of 60%

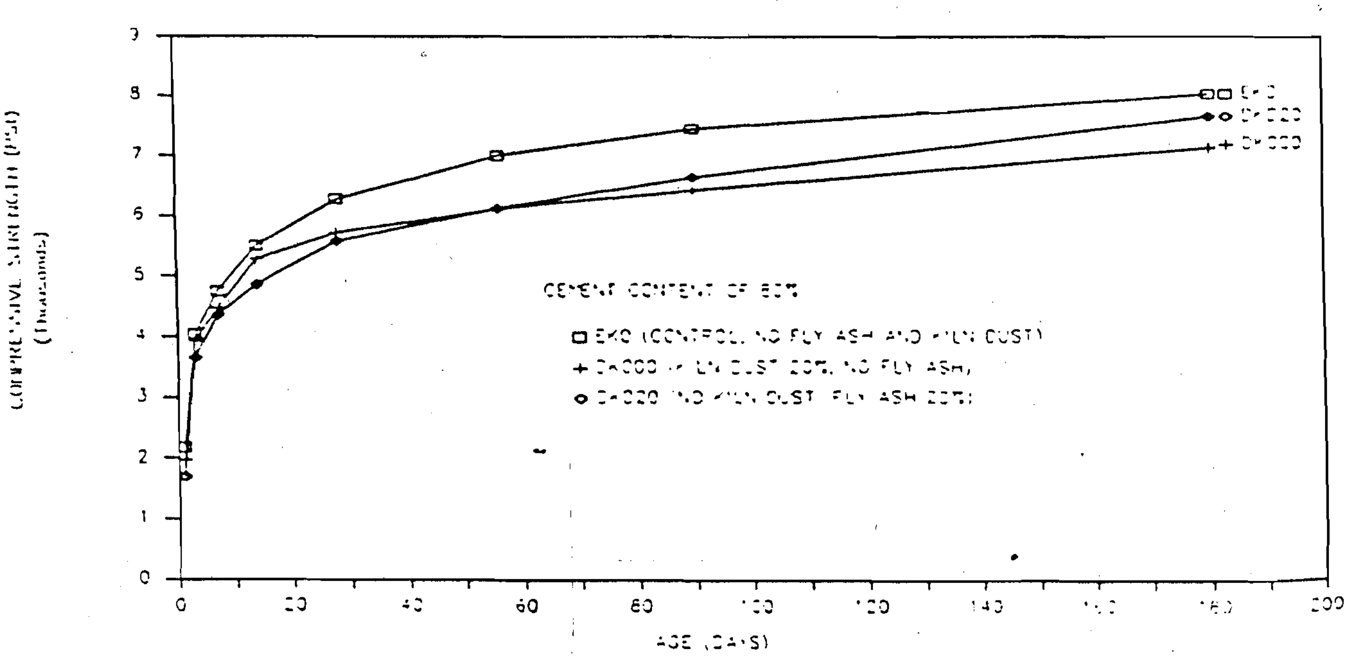

Fig. 4 Effect of Fly Ash-Kiln Dust on the Strength of Mortar with Cement Content of 80%

Optimum Mix of Cement-Fly Ash-Kiln Dust Mortar

Fig. 5 shows the relationship between percentage of fly ash in cementitious materials and compressive strength of cement-fly ash-kiln dust mortar at the age of 180 days. It can be seen that at low cement content of 20% and 40%, the use of fly ash or kiln dust alone does not give the highest strength. With constant cement content, the suitable combinations of fly ash and kiln dust are required to obtain the highest strength. For 20% cement content in the cementitious materials, the optimum amount of fly ash needed to produce the highest strength is about 40% (fly ash 40% and kiln dust 40%). For 40% cement content, the optimum mix consists of 40% fly ash and 20% kiln dust. With 60% cement content, the optimum mix is found to have 40% fly ash with no kiln dust. For the case of 80% cement content in cementitious materials, the optimum mix has 20% fly ash and no kiln dust.

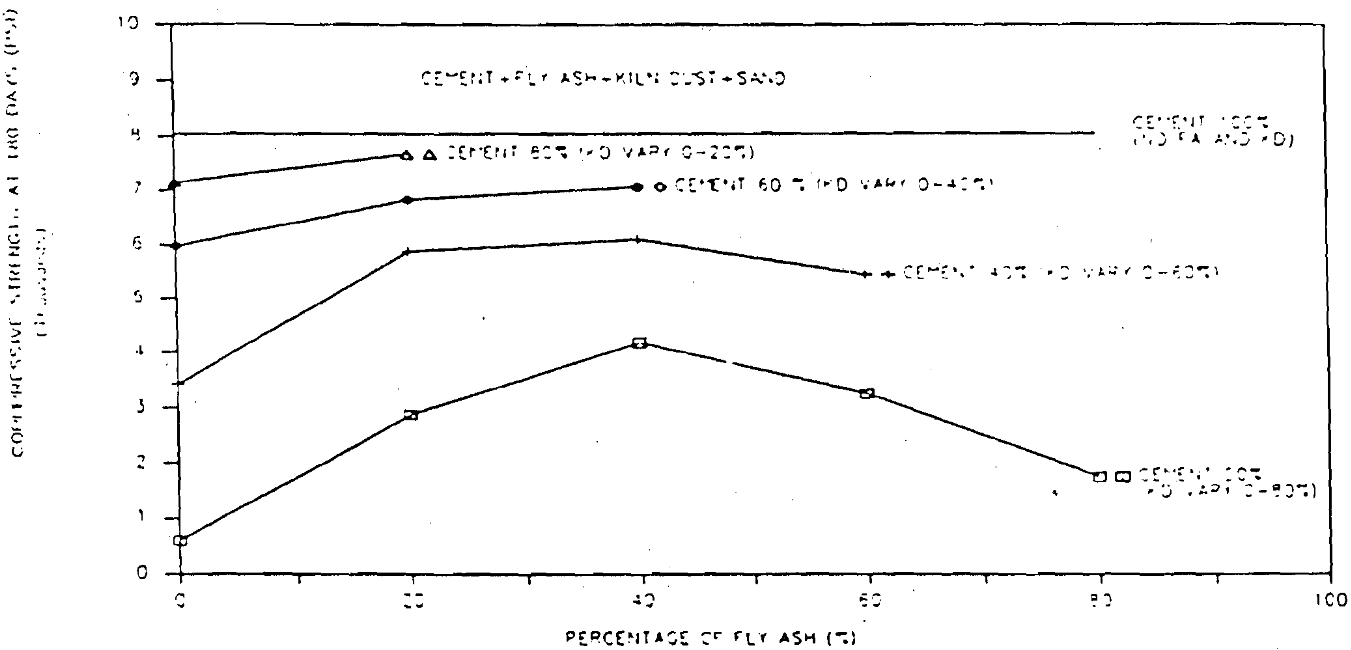

Fig. 5 Relationship between Percentage of Fly Ash in Cementitious Materials and Compressive Strength of Cement-Fly Ash-Kiln Dust Mortar at the Age of 180-Day

Setting Time

From Table 4, it can be observed that the normal consistency of the water to cement ratio varies from 28% in cement paste to 155.3% in sample AKD80 (with cement 20% and fly ash 80%). If considers normal consistency in term of water to cementitious materials ratio, this ratio is almost constant between 28% to 31%.

The shortest setting times observed in this experiment occur in cement paste. The initial and final setting times tested by the Vicat needle are 2 h 20 min and 5 h 30 min, respectively, and 2 h 40 min and 5 h 30 min, respectively by the Gillmore needles. The longest setting times observed occur in sample AKD80 which has initial and final setting times of 4 h 45 min and 10 h 15 min, by Vicat needle, and 4 h 50 min, 9 h 25 min, respectively, by Gillmore needles. Note that ASTM C-150 (4) specified that the initial setting time of cement paste tested by Vicat needle should not be less than 45 min and no more than 8 h for the final setting time. For the Gillmore test, the initial set should not be less than 60 min and no more than 10 h for the final set. In 1990, the Vicat method was revised to only specify the initial setting time to be between 45 min and 375 min, and no final setting time was specified (5). For the same amount of cement, the paste with higher percentage of kiln dust normally exhibits a shorter setting time than the paste with lesser kiln dust. This is primarily because kiln dust has a high content of CaO thus accelerates the setting time. However, the cementing property of kiln dust is not as strong as normal cement but is better than fly ash.

Table 4 Setting Time of Cement-Fly Ash-Kiln Dust Paste

Sam.	Normal Consistency (%)		Initial Setting		Final Setting	
	W/C	W/(C+FA+KD)	Vicat h:min	Gillmore h:min	Vicat h:min	Gillmore h:min
AK000	153.8	30.7	3:15	3:15	8:30	8:00
AKD20	151.0	30.2	3:50	4:00	8:45	8:20
AKD40	149.2	29.8	4:10	4:25	9:15	8:30
AKD60	151.5	30.3	4:30	4:45	9:40	9:10
AKD80	155.3	31.0	4:45	4:50	10:15	9:25
BK000	77.6	31.0	4:00	4:05	7:20	7:20
BKD20	76.2	30.5	4:10	4:10	7:40	7:30
BKD40	76.1	30.4	4:20	4:25	8:00	7:50
BKD60	75.3	30.1	4:25	4:25	8:05	8:05
CK000	49.7	29.8	3:25	3:35	6:25	6:35
CKD20	47.1	28.3	3:30	3:34	6:40	6:40
CKD40	48.7	29.2	3:35	3:55	7:55	8:00
DK000	35.5	28.4	2:30	2:50	5:50	6:00
DKD20	35.0	28.0	2:35	3:00	6:00	6:05
CEM	28.0	28.0	2:20	2:40	5:30	5:30

CONCLUSIONS

1. The higher the cement content in the mix, the higher the compressive strength of the cement-fly ash-kiln dust mortar is.
2. For mixes with a constant amount of cement, the proportion of fly ash and kiln dust must be adjusted to obtain the optimum compressive strength. For 20% constant cement content in cementitious materials, the optimum mix found is the sample with 40% fly ash and 40% kiln dust. For 40% constant cement series, the optimum mix consists of 40% fly ash and 20% kiln dust. In the 60% constant cement series, the optimum mix has 40% fly ash with no kiln dust. For the 80% constant cement series, the optimum mix observed has 20% fly ash and no kiln dust.
3. The lower the cement content, the longer is the setting time of the paste. Kiln dust which has some cementing properties generally accelerates the setting time. When the cement content is constant, the paste with a higher percentage of kiln dust has a shorter setting time than those with lesser kiln dust.

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