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TIME OF SETTING INFLUENCED BY FLY ASH AND CHEMICAL ADMIXTURES

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Time of Setting Influenced by Inclusion Of Fly Ash and Chemical Admixtures

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Synopsis: This investigation was performed to establish the effects of pozzolanic and chemical admixtures on setting behavior of cement paste at normal consistency. An ASTM Class C fly ash was used as a pozzolanic and cementitious admixture. Mixtures were proportioned to contain fly ash in the range of 0-100% by mass of the cementitious materials using a cement replaced by fly ash in a proportion of 1: 1.25. One source of ASTM Type I cement was used. The effects of five admixtures, air-entraining agent (AEA), water reducer, retarder, high-range water-reducer (HRWRA), and hemihydrate gypsum ($CaSO_4.1/2H_2O$) on setting characteristics of pastes, were investigated. Both initial and final setting times remained essentially the same or were slightly delayed up to 20% cement replacement with respect to the 0% fly ash mixture. Beyond this range, the times of setting were generally accelerated. Increased rate of setting occurred at cement replacement levels of 40 % and above irrespective of type of chemical admixtures used.

Keywords: AEA, fly ash; gypsum, HRWRA, paste, retarder, time of setting, water reducer.

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INTRODUCTION

Immediately upon mixing of cement and water various reactions occur leading to formation of numerous hydration products. The types and amount of hydration products formed depend upon duration of hydration, water to cementitious materials ratio, properties of constituent materials, temperature, soluble alkalis, chemical admixtures, etc. [1, 2]. The formation of hydration products cause increase in stiffness of cementitious matrix as a function of time. This stiffening behavior of the matrix is determined by initial and final times of setting. The initial time of setting of the matrix refers to the beginning of solidification for a given mixture. It is generally accepted that at this stage concrete can neither be properly re-tamped nor it can be handled and placed. The final setting refers to the stage when the mixture attains sufficient hardness to support stress. The rate of strength gain is called hardening.

Setting and hardening of cement mortar mixtures are considerably influenced by inclusion of both mineral and chemical admixtures. Generally, the setting and hardening of mortar is negatively affected when ASTM Class F fly ash is added to it. However, ASTM Class C fly ashes have shown both rapid and delay setting of concrete depending upon their properties and quantity used. The setting behavior can be more readily modified for concrete when chemical admixtures such water reducer, superplasticizer, retarder, gypsum, etc. are used in mixtures containing fly ash. A knowledge of setting characteristics of concrete incorporating both mineral and chemical admixtures is needed for efficient scheduling of concrete construction, specifically floor slabs, roadways, pavements, and other flat surfaces. Limited data exist on setting and hardening behavior of paste, mortar, and concrete containing ASTM Class C fly ash and various chemical admixtures. This research was primarily carried out to establish setting and hardening characteristics of cement paste as influenced by inclusion of Class C fly ash with and without chemical admixtures.

PREVIOUS INVESTIGATIONS

Set retarding tendency of Class F fly ash in concrete has been reported by Ramachandran et al. [2]. Class C fly ashes have shown mixed behavior in regard to setting characteristics of concrete. The initial and final times of setting may increase, decrease, or remain unaffected due to addition of Class C fly ash [1, 2].

Some studies [3, 4, 5] have shown significant effect of temperature on setting and hardening behavior of mortars and concrete made with and without fly ash. The initial and final times of setting decreased with an increase in temperature and/or water to cementitious materials ratio of mortars and concrete [3, 4]. Tay [6] performed a study to investigate properties of mortars and concrete as influenced by inclusion of sludge ash. The test data exhibited improved workability and increase in initial and final times of setting with increasing sludge ash content.

Pinto and Hover [7] studied the effects of inclusion of silica fume and superplasticizer on setting behavior of high-strength mixtures. The influence of temperature was also studied by storing mortar specimens at different temperatures. Use of silica fume caused reduction in the initial time of setting. However, an opposite trend was noted when superplasticizer was used. Statistical analysis revealed significant interaction between the two (silica fume and superplasticizer) when the initial time of setting was taken as a response. The effect of temperature was significant on both initial and final times of setting.

Samadi et al. [8] studied the influence of phosphogypsum (PG) on the times of setting and soundness of cement pastes. In this study, cement paste mixtures were made using ordinary portland cement (OPC) and pozzolanic portland cement (PPC) at a constant water to cement ratio of 0.6 with PG content varying between 0 and 100 percent. In general both initial and final times of setting increased with increasing PG content. The initial time of setting ranged between 100 to 560 minutes and 120 to 710 minutes for pastes containing OPC and PPC, respectively. The corresponding final time of setting ranged between 250 to 1440 minutes and between 270 to 1440 minutes. The paste expansion also increased with increasing PG content. Matusinovic and Curlin [10] and Matusinovic and Vrbos [11] reported that setting characteristics of high alumna cement (HAC) were substantially influenced by inclusion of alkali metal salts. The lithium cation had a greater effect on the times of setting than alkali cations did. The results showed that lithium salt [10] or alkali metal salts [11] could be used as a set accelerator for HAC.

Chen and Older [12] investigated the effect of cement varying in clinker composition with varying amounts and forms of calcium sulfate on the times of setting of mortars. They indicated that the setting of cement having normal composition is mainly related to hydration of C_3S Content. The formation of enttringite occurred at very high C_3A contents. Uchikawa et al. [13] evaluated the effects of chemical admixtures on hydration characteristics of cement. The authors reported that an admixture having a functional group that produces complex salt with decrease in Ca^{2+} concentration can cause loss in fluidity and delay in the times of setting of cement pastes. Sawan and Qasrawi [14] concluded that the use of natural pozzolan would cause decrease in workability and increase in the times of setting of mortar under normal condition. However, an opposite trend was obtained in hot weather conditions.

EXPERIMENTAL PROGRAM

An experimental program was designed to evaluate the effects of Class C fly ash and chemical admixtures on setting and hardening characteristics of cement paste. Four series of experiments were conducted. The first series of experiments were conducted to evaluate only the effects of fly ash addition on the setting characteristics of cement paste. The second series of experiments were conducted to evaluate the effects of fly ash and air content on the times of setting of cement paste. The third series of experiments were conducted to evaluate the influence of fly ash and normal dosage of chemical admixtures on the setting behavior of cement paste. The fourth series of experiments were performed to establish the combined effects high dosage of fly ash and chemical admixtures on the setting characteristics of cement paste.

A portland cement conforming to the requirements of ASTM C 150 was used. An ASTM Class C fly ash, obtained from one source, Wisconsin Electric's plant at Pleasant Prairie (P-4), was used. The fly ash met all ASTM C 618 requirements for Class C fly ash (Table 1). Five chemical admixtures: an air entraining admixture (ASTM C 260), a water reducer (ASTM C 494, Type A), a retarder (ASTM C 494, Type B), and a superplasticizer (ASTM C 494, Type F) were obtained from the Tews Company, Milwaukee, WI.

MIXTURE PROPORTIONS

A total of 82 cement paste mixtures were prepared for evaluating their setting and hardening characteristics. Each mixture was composed of cement, fly ash, and water. Fly ash was used as a replacement of cement ranging from 0 to 100 percent by mass as shown in Table 2. A ratio of fly ash addition to cement replaced was kept at 1.25. Due to lower reactivity of fly ash compared to portland cement, inclusion of fly ash as a replacement of cement causes dilution of the cementitious materials leading to potentially decreased reactivity. The higher amount of fly ash was used to account for change in specific gravity between cement replaced and fly ash substitution, and to compensate for the potential decrease in the reactivity of the cementitious materials. The resulting mixture proportions are given in Table 2. In this paper, nominal fly ash content reported is designated as the percentage of cement replacement.

MIXING, SPECIMEN PREPARATION, AND TESTING

All ingredients were mixed in a laboratory mixer in accordance with ASTM C 305. Normal consistency of pastes containing cement/fly ash was determined in accordance with ASTM C 187. Air content of each mixture was determined according to ASTM C 185. Test specimens for each mixture were prepared for measuring the initial and final times of setting using the Vicat apparatus (ASTM C 191). This apparatus measures paste resistance to the penetration of a needle under a load of 300 g. The initial time of setting is measured as the time required for the Vicat needle to penetrate to a depth of 25 mm. The final time of setting is the time required to reach a stage when the Vicat needle does not visibly penetrate into the paste.

RESULTS AND DISCUSSION

The results derived from the four series of experiments are given in Tables 3 though 9 and Figs. 1 through 5. In all series of experiments, fly ash content was varied from 0 to 100% of total cementitious materials.

Series 1 - Effect Of Fly Ash on Setting Characteristics of Pastes without Any Admixtures

Test data show that water demand for Series 1 mixtures, Table 3 and Fig.1, decreased 30% with increasing fly ash content. The initial and final times of setting were essentially the same due to the inclusion of fly ash at 10% (Table 3 and Figs. 2 and 3) compared to the 0% fly ash mixture (Table 2). Beyond 10% fly ash content, accelerated setting occurred and the rate of setting increased with fly ash content. Very rapid rate of setting and hardening occurred at 40% fly ash content and above. The entrapped air content was essentially the same for all mixtures at about 6.5 ± 0.5 percent. The accelerated setting at high fly contents are due to the several factors as described below.

ASTM Class C fly ash contains calcium in the form of reactive crystalline phases such as CaO, C_3A, C_2S, C_3S, and $C4A_3S'$ (S' = SO_3). The presence of calcium ions tend to increase reactivity of the glassy phase (noncrystalline phase) of the fly ash [9]. Takemoto et al. [16, 17] described a model for hydration reaction process of cement in the presence of pozzolans. The reactions of C_3A from cement and Class C fly ash are similar to that of reactions between C_3S from cement and Class C fly ash. The reactions of C_3A and Class C fly ash result in formation of enttringite, monosulphoaluminate hydrate, calcium aluminate hydrates, and calcium silicate hydrate. The authors reported that presence of pozzolan accelerated hydration of C_3A due to adsorbing Ca^{2+} from the liquid phases and providing precipitation sites for the hydration products. Malhotra et al. [18] have reported that inclusion of Class F fly ash retards the hydration of C_3S at very early stages of hydration and then accelerate at later stages.

C_3A contribution from this fly ash increased with increasing its content as a replacement of cement. Thus, fly ash also became a contributor of C_3A and other reactive components at high fly ash contents. Accelerated setting and hardening occurred due to the reactions of C_3A present in the fly ash in addition to contributions of the above-mentioned reactions associated with cement hydration in presence of fly ash at cement replacements of about 40% and above. Extremely high rate of setting and hardening at 70% fly ash content and beyond occurred due to the presence of relatively higher amount of C_3A contributed by the fly ash, in addition to that contributed by cement. Hydration of aluminates is very rapid leading to formation of C_3AH_6, C_4AH_{19}, and C_2AH_8 with generation of large amount of heat of hydration [9].

Series 2 - Effect Of Air Content on Setting Characteristics

In this series of tests, experiments were performed to establish the effects of air content on setting characteristics of fly ash mixtures. Dosage of air entraining was varied to entrain air in these mixtures at low (about 18%) air and high (about 24%) levels (Tables 4 and 5). The amount of air-entraining admixture required at the low air content level was about half of that required for the high air content level. The water demand decreased as the fly ash content increased for mixtures containing AEA at both the air content levels (Tables 4 and 5). Generally, the use of AEA caused decrease in water demand by approximately 20% to 30% relative to fly ash mixtures without AEA (Table 3). However, between low air and high level use of AEA, Tables 4 and 5, the water demand was essentially the same.

At the low air content level, the time of settings were essentially the same up to 20% fly ash content, beyond which the times of setting were accelerated. Very high rate of setting occurred at 40% fly ash content and beyond. Thus at high fly ash contents, setting characteristics of air-entrained mixtures (Tables 4) followed a similar general trend as indicated by the fly ash mixtures without AEA (Table 4) as described previously. At the high air content level, the general setting characteristics of fly ash mixtures (Table 5) remained the same as that obtained at the low air content level (Table 4). The use of AEA caused retardation for some mixtures in both initial and final times of setting, Tables 4 and 5, relative to non-air entrained mixtures, Table 3. This may be probably due to the fact that AEA make cement particle hydrophobic leading to retardation in the hydration of cementitious materials [9].

Series 3 - Effect of Fly Ash with Normal Dosages of Chemical Admixtures on Setting Characteristics

In this series of tests, fly ash content varied from 0 to 100% with normal dosages of individual chemical admixtures, Tables 6, 7, and 8. The combined effects of fly ash and the chemical admixture on setting behavior are addressed in the following sections.

Fly Ash with a Normal Dosage of Water Reducer--The water demand decreased with an increase in fly ash content for pastes containing the water reducer (Table 6). Inclusion of the water reducer caused reduction in the water demand for these mixtures (Table 6) compared to the mixtures without water reducer (Table 3).

The combined effect of fly ash and water reducer was significant on the times of setting of pastes. Both initial and final times of setting were reduced up to fly ash content of 20%, Table 6. Beyond 20% fly ash content, the setting was accelerated. High rates of setting occurred at 40% fly ash content and above. The setting and hardening behavior of mixtures with the water reducing admixture, Table 6, is similar to the mixtures, made with fly ash alone, Table 3. Inclusion of water reducer (Table 6) caused reduction in the times of setting of Mixtures 1 and 2 compared to the mixtures without water reducer (Table 3). The hydration reaction was accelerated due to the reduction in water to cementitious materials ratio, as well as more cement particles hydrating early due to dispersion of the cementitious particles when the water reducing admixture was used. However, the degree of acceleration or retardation caused by the admixtures depend upon their chemical make-up.

Fly Ash with a Normal Dosage of Superplasticizer-- In general, water demand for superplasticized mixtures decreased with increasing fly ash content (Table 7). As expected, the use of superplasticizer caused reduction in water demand (Table 7) relative to fly ash mixtures without any admixtures (Table 3). The combined effect of fly ash and superplasticizer was a noticeable reduction in the times of setting, Table 7, similar to other mixtures. However, the use of superplasticizer did not cause appreciable difference in the times of setting of the mixtures (Table 7) compared to unsuperplasticized mixtures (Table 3).

Fly Ash with a Normal Dosage of Retarder--The water demand for mixtures with retarder decreased with increasing fly ash content (Table 8). Inclusion of the retarder in mixtures resulted in slight decrease in water demand (Table 8) compared to the mixtures without any admixtures (Table 3).

The time of setting for mixtures containing the retarder was delayed for fly ash content up to 20% (Table 8). Beyond these fly ash levels, the corresponding setting times were not much helped by the use of the retarder. The rate of setting became very high at 50% fly ash content and above. At high fly ash contents, general trend of setting and hardening of paste mixtures remained similar as that obtained for the fly ash mixtures without retarder (Table 3). Addition of the retarder (Table 8) caused increase in the times of setting compared to mixtures without retarder (Table 3), especially at high fly ash content.

Fly Ash with a Normal Dosage of Gypsum--The water demand for gypsum mixtures decreased with increasing fly ash content (Table 9). The use of gypsum (Table 9) caused reduction in water demand relative to the mixtures without gypsum (Table 3). The results show no significant difference in the initial and final setting times of the mixtures up to 10% fly ash content when gypsum was used (Table 9). Beyond 10% fly ash content, the times of setting decreased for gypsum mixtures with increasing fly ash content, Table 9. The general setting behavior of mixtures (Table 9) followed essentially similar trend as indicated by fly ash mixtures without gypsum (Table 3). Inclusion of gypsum in the fly ash mixtures (Table 9) caused a very noticeable reduction of the initial and final setting times compared to the mortar mixtures without gypsum (Table 3).

Series 4 - Effect of High Fly Ash Contents with High Dosages of Chemical Admixtures on Setting Characteristics

At high fly ash content (above 40%), very rapid rate of setting of mixtures occurred. Use of normal dosage of retarder and gypsum did not cause enough delay to compensate for the rapid rate of setting resulting from the presence of the fly ash. Therefore, in this series of tests, high dosages of these admixtures were used at fly ash contents of 70, 85, and 100%. The retarder and gypsum were used at their respective double and triple dosages for this series of investigation.

Fly ash with Retarder--In general, when the amount of the retarder increased beyond normal dosage, the initial and final times of setting were considerably delayed, especially for 85% and 100% fly ash levels (Table 8). At the double dosage of the retarder, the final time of setting increased from 47 to 54 minutes at 70% fly ash content, from 37 to 42 at 85% fly ash content, and 14 to 35 minutes at 100% fly ash content. When dosage of the retarder was increased from normal to triple dosage, the final time of setting decreased from 47 to 37 minutes at 70% fly ash content and increased from 37 to 43 minutes at 85% fly ash content, and 14 to 54 minutes at 100% fly ash content. These results show that a delay in the times of setting can be achieved even at 100% fly ash level with high dosage of the retarder. Under this condition, the final time of setting was delayed by over 300 % compared to the normal dosage of the retarder. However, the rate of setting was still very high even at the triple dosage of the retarder.

Fly Ash with Gypsum--Due to very rapid setting, initial time of setting could not be recorded at the fly ash content of 70% and beyond at the normal dosage of gypsum, probably due to early enttringite formation. However, when dosage of gypsum was doubled or tripled, initial times of setting, though not slow enough, could only be recorded for the fly ash levels of 70% and 85% (Table 9). At double dosage of gypsum, the final setting time increased from 15 to 40 minutes at 70% fly ash content, from 15 to 27 minutes at 85% fly ash content, and from 10 to 13 minutes at 100% fly ash content compared to that at the normal dosage. Thus, the use of high dosage of gypsum did not help significant in modifying the setting characteristic of mixtures incorporating fly ash (Table 9).

CONCLUSIONS

The following conclusions may be drawn based on the results obtained in this investigation.

1. The water demand of mixtures decreased with increasing fly ash content. Further decrease in the water demand occurred when admixtures were used.

2. Inclusion of fly ash caused small delay in the initial and final times of setting up to 20% fly ash content depending upon type of chemical admixtures used. Beyond this limit, the setting was accelerated.

3. Extremely high rates of setting occurred at fly ash content of about 40% and beyond depending upon type of chemical admixtures used.

4. Use of AEA caused retardation in the initial and final times of settings in some mixtures with compared to non-air entrained mixtures.

5. Use of normal dosages of water reducer and gypsum caused acceleration in the setting of paste. However, no appreciable effect of normal dosage of superplasticizer on the setting was obtained.

6. As expected, inclusion of the retarder caused delay in the setting times compared to mixtures without retarder.

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List of Tables and Figures

Table 1 - Properties of Fly Ash

Chemical composition (%)		ASTM C 618, Class C Fly Ash
Silicon dioxide, SiO_2	32.2	-
Aluminum oxide, Al_2O_3	18.1	-
Ferric oxide, Fe_2O_3	5.6	-
Total, $SiO_2 + Al_2O_3 + Fe_2O_3$	55.9	50.0 min.
Sulfur trioxide, SO_3	2.6	5.0 max.
Calcium oxide, CaO	31.9	-
Magnesium oxide, MgO	4.7	
Titanium dioxide, TiO_2	1.6	-
Potassium oxide, K_2O	0.3	-
Available alkalies, as Na_2O	-	1.5 max.
Moisture content	-	3.0 max.
Loss on ignition	0.9	6.0 max.
Mineralogical Composition (%)		-
Quartz, SiO_2	10.0	-
Dicalcium Silicate, C_2S	2.1	-
Tricalcium Aluminate, C_3A	11.0	-
Lime, CaO	1.6	-
Anhydrite, $CaSO_4$	1.0	-
Periclase, MgO	2.9	-
Amorphous	70.8	-
Physical Properties		-
Fineness retained on No. 325 sieve (%)	25.5	34 max.
Pozzolanic activity index with cement, 28-day (% of control)	85.4	75 min.
Water requirement (% of control)	97.1	105 max.
Autoclave expansion (%)	0.04	0.8 max.
Specific gravity	2.58	-

Table 2 - Fly Ash Contents for Various Mixtures

Mixture Number	Fly Ash* (%)	Cement (Grams)	Fly Ash (Grams)
1	0	650	---
2	10	585	81
3	20	520	163
4	30	455	244
5	40	390	325
6	50	325	406
7	60	260	488
8	70	195	569
9	85	98	691
10	100	---	813

*Fly ash content is expressed as percentage of the cement replacement. The ratio of fly ash to cement replaced was kept at 1.25: 1

Table 3 - Mixtures Incorporating Fly Ash Without Any Admixtures

Mixture Number	Fly Ash (%)	Times of Setting		Water Content (ml)	Air Content* (%)
		Initial (Hour:Min.)	Final (Hour:Min.)		
1	0	3:50	4:15	244	6.7
2	10	3:45	4:02	234	6.7
3	20	1:49	2:05	227	6.9
4	30	1:00	2:10	220	7.1
5	40	0:17	0:48	213	7.1
6	50	0:15	0:45	206	7.4
7	60	0:10	0.19	199	7.5
8	70	0:11	0:19	192	7.6
9	85	0:07	0:10	185	7.7
10	100	----	0:05	178	5.8

*Entrapped air only (i.e., air entraining agent was not used)

Table 4 - Mixtures Incorporating Fly Ash and Air-Entraining Admixture (Low Air Level)

Mixture Number	Fly Ash (%)	AEA (ml)	Times of Setting		Water Content (ml)	Air Content (%)
			Initial (Hour:Min.)	Final (Hour:Min.)		
1	0	1.0	4:10	4:55	196	19.8
2	10	1.0	3:50	4:25	186	18.1
3	20	1.2	4:15	5:00	181	20.0
4	30	1.6	2:00	2:40	173	18.9
5	40	1.6	0:50	2:00	166	18.1
6	50	1.6	0:41	1:48	159	16.8
7	60	2.0	0:15	1:01	155	18.0
8	70	2.0	0:10	0:15	147	19.3
9	85	2.0	0.08	0.20	141	17.7
10	100	3.4	----	0:07	123	16.9

Table 5 - Mixtures Incorporating Fly Ash and Air-Entraining Admixture (High Air Level)

Mixture Number	Fly Ash (%)	AEA (ml)	Times of Setting		Water Content (ml)	Air Content (%)
			Initial (Hour:Min.)	Final (Hour:Min.)		
1	0	1.8	3:00	4:30	198	25.1
2	10	2.2	4:30	5:15	184	24.2
3	20	2.6	4:40	5:25	170	22.4
4	30	3.0	1:50	4:05	164	25.3
5	40	3.6	1:20	2:40	151	23.3
6	50	4.4	0:45	1:35	144	23.0
7	60	5.8	0:20	1:00	141	23.6
8	70	6.4	0:10	0:50	137	24.1
9	85	7.0	0.05	0.15	135	23.4
10	100	7.6	----	0:05	129	23.7

Table 6 - Mixtures Incorporating Fly Ash and Water Reducer (150 ml/cwt (3 liq. oz./cwt))

Mixture Number	Fly Ash (%)	Times of Setting		Water Content (ml)	Water Content (%)
		Initial (Hour:Min.)	Final (Hour:Min.)		
1	0	1:47	2:30	164	25
2	10	2:15	3:08	158	24
3	20	2:30	3:55	156	23
4	30	1:06	1:50	155	22
5	40	0:30	1:15	153	21
6	50	0:30	0:50	150	21
7	60	0:17	0:40	147	20
8	70	0:15	0:35	140	18
9	85	0:12	0:25	134	17
10	100	----	0:15	132	16

Table 7 - Mixtures Incorporating Fly Ash and Superpalsticizer (598 ml/cwt (12 liq. oz./cwt))

Mixture Number	Fly Ash (%)	Times of Setting		Water Content (ml)	Water Content (%)
		Initial (Hour:Min.)	Final (Hour:Min.)		
1	0	3:15	3:30	164	25
2	10	3:45	4:10	163	24
3	20	2:50	3:25	165	24
4	30	1:10	2:10	166	24
5	40	0:30	0:55	150	21
6	50	0:20	0:25	142	19
7	60	0:15	0:30	140	19
8	70	0:03	0:20	136	18
9	85	0:08	0:25	134	17
10	100	----	0:15	131	16

Table 8 - Mixtures Incorporating Fly Ash and Retarder[a]

Mixture Number	Fly Ash (%)	Times of Setting		Water (ml)	Water Content (%)
		Initial (Hour:Min.)	Final (Hour:Min.)		
1	0	3:05	3:45	174	27
2	10	3:42	4:22	168	25
3	20	3:00	3:55	166	24
4	30	1:15	2:12	155	22
5	40	0:47	1:47	151	21
6	50	0:18	0:52	146	20
7	60	0:12	0:27	140	19
8	70	0:20	0:47	140	18
9	85	0:10	0:37	139	18
10	100	----	0:14	135	17
[b]11	70	0:28	0:54	137	18
[b]12	85	0:30	0:42	131	17
[b]13	100	0:26	0:35	128	16
[c]14	70	0:17	0:37	131	17
[c]15	85	0:23	0:43	130	17
[c]16	100	0:44	0:54	129	16

[a] Normal dosage of 150 ml/cwt (3 liq. 0z./cwt)

[b] Mixture Number 11, 12, and 13: Double dose of retarder used

[c] Mixture Number 14, 15, and 16: Triple dose of retarder used

Table 9 - Mixtures Incorporating Fly Ash and Gypsum [a]

Mixture Number	Fly Ash (%)	Times of Setting		Water Content (ml)	Water Content (%)
		Initial (Hour:Min.)	Final (Hour:Min.)		
1	0	2:50	3:15	186	29
2	10	2:40	3:10	180	27
3	20	1:45	2:30	176	26
4	30	0:50	1:50	170	24
5	40	0:35	1:00	166	23
6	50	0:10	0:30	160	22
7	60	0:15	0:35	157	21
8	70	----	0:15	156	20
9	85	----	0:15	154	20
10	100	----	0:10	153	19
[b]11	70	0:23	0:40	164	22
[b]12	85	0:15	0:27	162	21
[b]13	100	----	0:13	160	20
[c]14	70	0:27	0:35	176	23
[c]15	85	0:08	0:30	174	22
[c]16	100	----	0:13	172	21

[a] Normal dosage of 3 kg/cwt (4 lbs/cwt)

[b] Mix No. 11, 12, and 13: Double dose of gypsum used.

[c] Mix No. 14, 15, and 16: Triple dose of gypsum used.

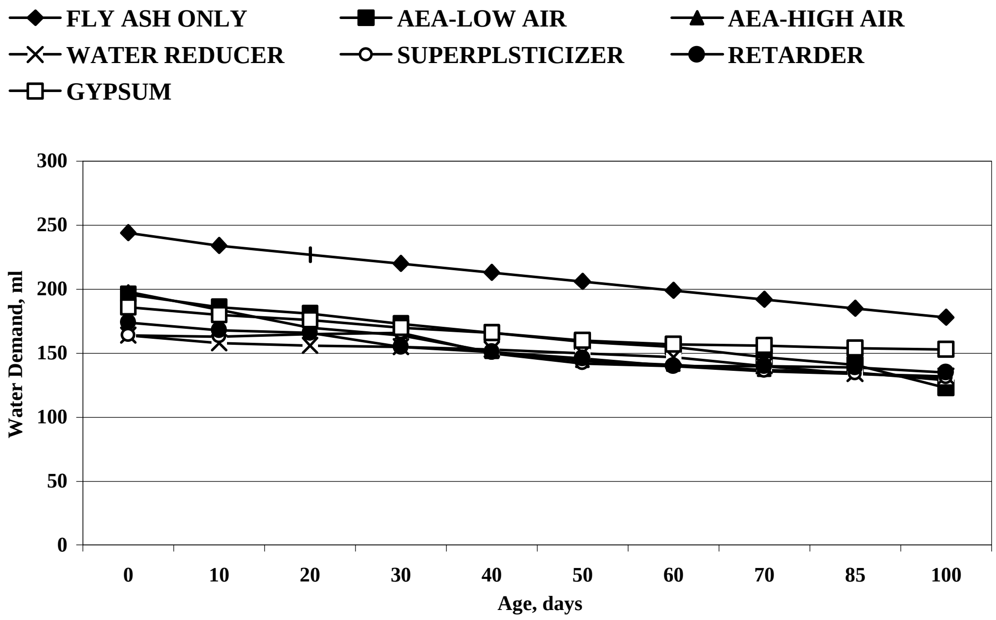

Fig. 1. Water Demand for Fly Ash Mixtures at Normal Consistency

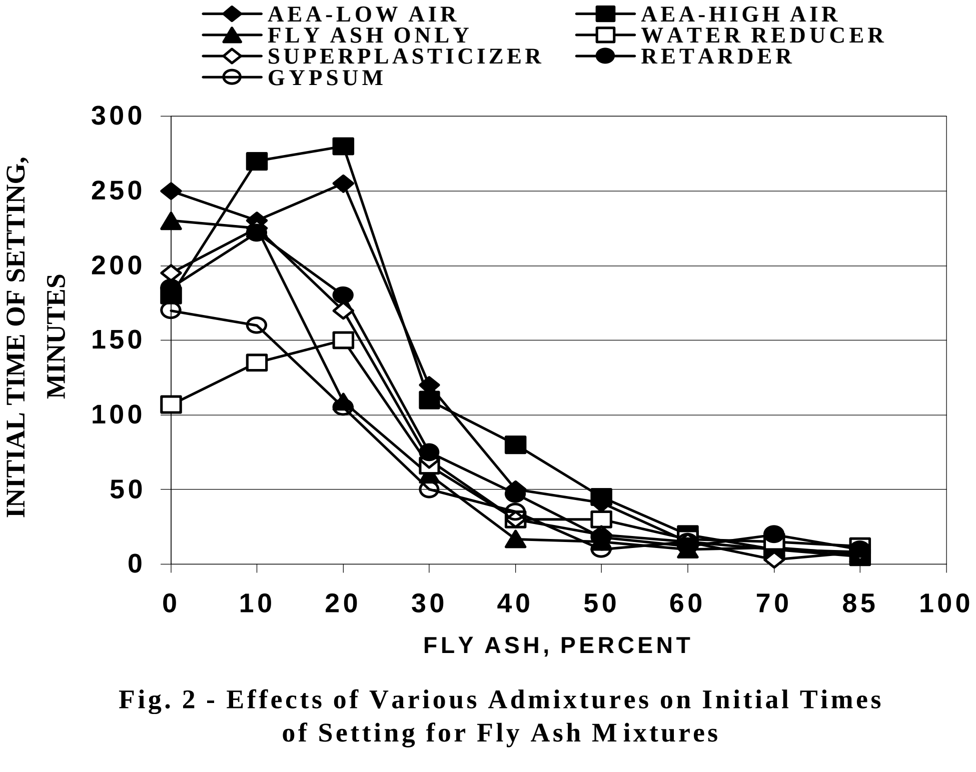

Fig. 2 - Effects of Various Admixtures on Initial Times of Setting for Fly Ash Mixtures

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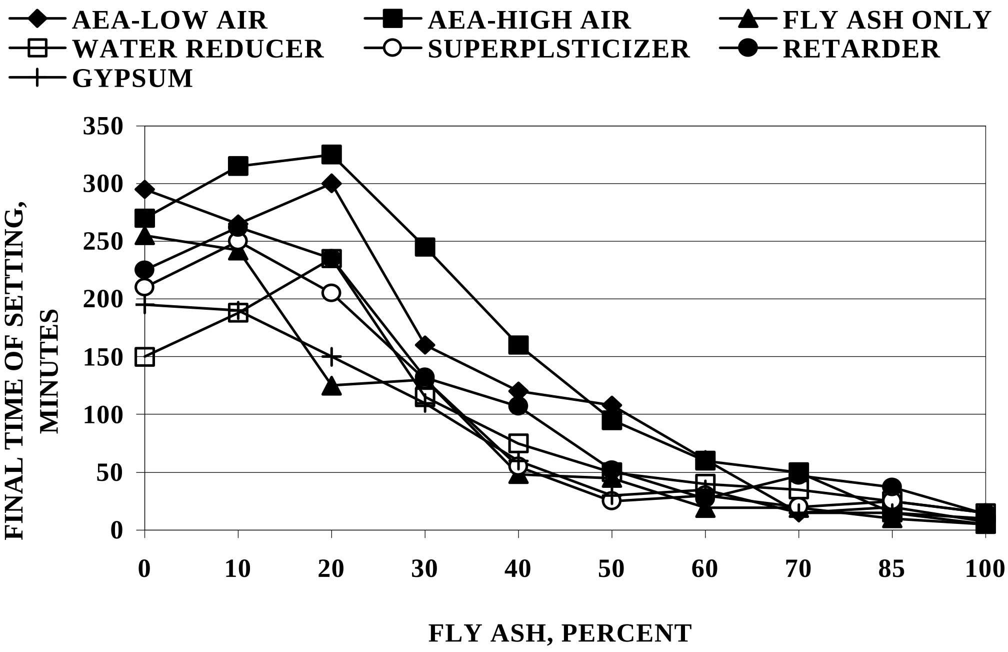

Fig. 3. Effects of Various Admixtures on Final Time of Setting for Fly Ash Mixtures

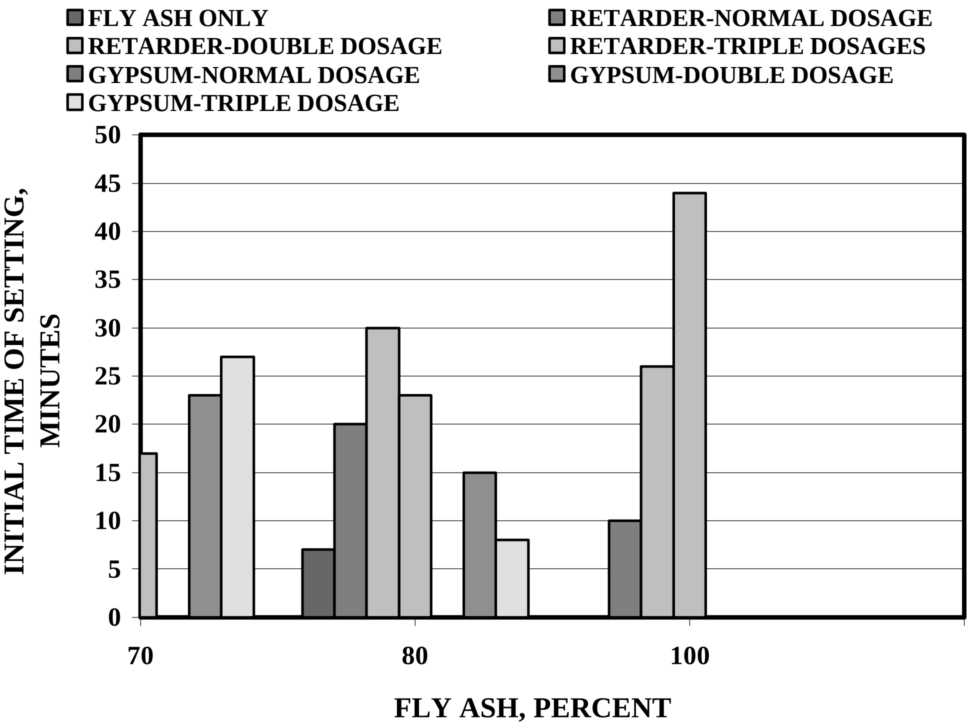

Fig. 4 - Effects of High Dosage of Admixtures on Initial Time of Setting for Fly Ash mixtures

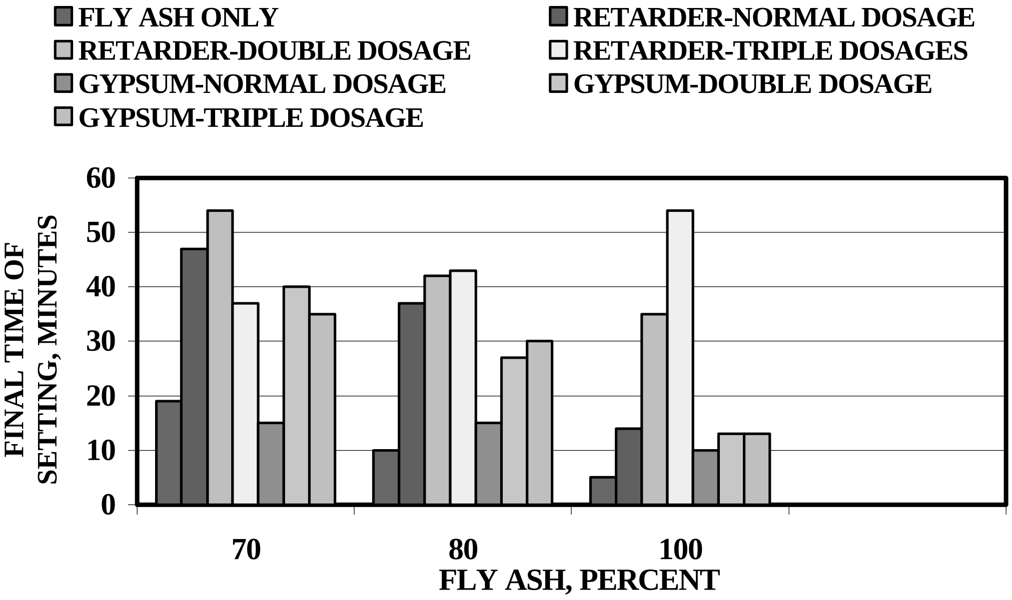

Fig. 5. Effect of High Dosage of Admixtures on Time of Final Setting for Fly Ash Mixtures