บทบาทของเถ้าถ่านหินแบบแห้งและแบบ WEATHERED ในปูนซีเมนต์

โดย

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RP-75

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DRY AND WEATHERED FLY ASH ON CEMENT-BASED MATRICES

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บทคัดย่อ

เถ้าถ่านหินแบบแห้งโดยทั่วไปจะเก็บไว้ในไซโลเพื่อที่จะขายได้ทันทีเมื่อมีผู้ต้องการซื้อ ส่วนเถ้าถ่านหินแบบแปรเปลี่ยนรูปแล้ว (Weathered) คือเถ้าถ่านหินแบบแห้งที่มีมากจนเหลือที่จะเก็บไว้ในไซโลได้และจำเป็นต้องทิ้ง เถ้าถ่านหินเหล่านี้จะผสมกับน้ำจากแม่น้ำซึ่งอยู่ใกล้เคียง จากนั้นปั๊มลงสู่บ่อซึ่งเตรียมไว้

เถ้าถ่านหินแบบ Weathered นี้จะทิ้งอยู่ในบ่อประมาณ 6 ถึง 12 เดือนจนกระทั่งบ่อเต็ม จึงทำการขนไปทิ้ง

เนื่องจากเถ้าถ่านหินแบบ Weathered นี้อยู่ในสภาพเปียกชื้นเป็นเวลานาน ซึ่งอาจทำให้สภาพของเถ้าถ่านหินชนิดนี้แปรเปลี่ยนไป และอาจทำให้เกิดปฏิกิริยาได้เร็วกว่าการใช้เถ้าถ่านหินแบบแห้ง ดังนั้นงานวิจัยนี้จึงมุ่งศึกษาถึงประสิทธิภาพของเถ้าถ่านหินแบบแห้งและแบบ Weathered เมื่อใช้ในส่วนผสมของปูนซิเมนต์ งานวิจัยนี้ใช้เถ้าถ่านหินเป็น 2 ลักษณะคือ ใช้แทนปูนซิเมนต์บางส่วน กับใช้ใส่เพิ่มเข้าไปในส่วนผสมของปูนซิเมนต์โดยตรง จากนั้นทำการทดสอบกำลังอัดของมอร์ต้าที่มีเถ้าถ่านหิน เพื่อเปรียบเทียบกับมอร์ต้าที่มีแต่ปูนซิเมนต์เท่านั้น ที่อายุ 1, 3, 7, 14, 28, 56, 90 และ 180 วัน นอกจากนี้ยังทำการหาส่วนประกอบทางด้านเคมีของเถ้าถ่านหินทั้ง 2 แบบนี้ รวมถึงการทดสอบ การก่อตัวของซีเมนต์เพสต์ที่มีเถ้าถ่านหินทั้ง 2 แบบนี้ผสมอยู่ด้วย ผลการทดลองพบว่า การใช้เถ้าถ่านหินแบบแห้งให้ค่ากำลังอัดสูงกว่าแบบ Weathered การใช้เถ้าถ่านหินเพื่อแทนปูนซิเมนต์นั้น จะลดค่ากำลังอัดของมอร์ต้าที่ช่วงอายุต้นๆ โดยทั่วไปเมื่อใส่เถ้าถ่านหินเพิ่มเข้าไปในส่วนผสมโดยตรง จะทำให้ค่ากำลังอัดสูงกว่าค่ากำลังอัดของมอร์ต้าที่ใช้เป็นตัวเปรียบเทียบ การใช้เถ้าถ่านหินในส่วนผสมเพื่อแทนปูนซิเมนต์นั้น จะยืดเวลาการก่อตัวเริ่มแรกและการก่อตัวครั้งสุดท้ายออกไป การศึกษาทางด้านเคมีพบว่าส่วนประกอบทางด้านเคมีของเถ้าถ่านหินแบบแห้ง และแบบ Weathered เปลี่ยนแปลงน้อยมาก นอกจากนี้ยังพบว่าตัวแปรที่สำคัญอันหนึ่งที่มีผลต่อการทำปฏิกิริยา คือขนาดของอนุภาคของเถ้าถ่านหิน ดังนั้นการเปลี่ยนแปรสภาพผลึกของเถ้าถ่านหินแบบ Weathered จึงมีผลน้อยมากต่อค่ากำลังอัดของเถ้าถ่านหินในงานคอนกรีต

SUMMARY

Dry fly ash, fly ash coming out from the electrostatic precipitator, was normally collected in the storage silo and used directly when demand exists. Weathered fly ash, the unused fly ash to be disposed of as waste, was commonly mixed with water from a nearby river and pumped to the storage ponds. This weathered fly ash was often kept in the pond for a period of at least 6 to 12 months until the pond was filled and subsequently disposed to the landfill.

Since weathered fly ash was kept under a wet condition for a long period of time, it is believed that the glassy phase may have been resolved and therefore the weathered fly ash may be more reactive than the dry fly ash. The effect of dry and weathered fly ashes on the properties of cementitious materials is then investigated here. Dry and weathered fly ash were used as a replacement and as an additive to cement-mortar mix. Compressive strength of the fly ash mortar and control mortar were tested at ages of 1, 3, 7, 14, 28, 56, 90, and 180 days. In addition, the chemical composition of the fly ashes and the setting time of these fly ash cement based matrices were also investigated.

The results show that dry fly ash gives higher compressive strength than weathered fly ash. The replacement of fly ash in mortar reduces the compressive strength at the early ages. Usually, the addition of fly ash in the mix produces higher compressive strength of mortar than the control mix at all ages. The use of fly ashes in the mix prolongs the initial and final setting time of fly ash-cement paste. The study of chemical composition of fly ashes reveals that the main constituents of weathered fly ash was not affected when stored under wet condition in the pond. It was found that one of the key parameters affecting the reactivity of fly ash in cement-based matrices may be the particle size and its distribution of fly ash. The resolved glassy phase of fly ash shows no significant effect on the overall strength development of fly ash concrete.

INTRODUCTION

ACI 116R defines fly ash as "the finely divided residue resulting from the combustion of ground or powdered coal which is transported from the firebox through the flue gases" [1]. Although it was originally identified as an artificial pozzolan, fly ash is now used as a part of the composite that forms the concrete mass, used as a substitute for binder and/or the aggregates of concrete. Regardless of what it substitutes for in concrete fly ash is known to affect all aspects of concrete properties [2].

The pozzolanic reaction is the reaction between constituents of the glass phase of the fly ash and calcium silicates. It is generally assumed to take place on the surface of fly ash particles, between silicates and aluminates from the glass phase and hydroxide ion in the pore solution [3]. As a pozzolan, it is essential that fly ash be in a finely divided state as it is only then that silica can combine with calcium hydroxide (liberated by the hydrated portland cement) in the presence of water to form stable calcium silicates with cementitious properties [4]. During the hydration portland cement produces a surfeit of lime that is released to the pore spaces. Excessive lime weakens the concrete mass by making it more vulnerable to acid, carbon dioxide and sulfate attacks. He Jun-yuan, Scheetz, and Roy [5] showed that the content of crystalline calcium hydroxide in the fly ash-portland cement pastes is decreased as a result of the addition of fly ash. This is most likely resulting from the additional reaction of the calcium with alumina and silica from the fly ash to form additional calcium-silicate-hydrate (C-S-H). Fly ash due to its fineness gets in the pore spaces and combines with this lime to produce C-S-H, unlike the hydrates of cement. This process stabilizes the concrete, reduces permeability and increases resistance to chemical attacks. In considering pozzolans in general, we should note that silica in fly ash has to be amorphous, as crystalline silica has very low reactivity.

In general, fly ash has been used as partial replacement of cement, fine aggregate, cement and fine aggregate, or fine and coarse aggregate [6]. At present the construction industry utilizes fly ash in two distinct ways, as a raw material for cement and as a constituent material for concrete. Usually fly ash used in concrete is collected dry and stored in the silo. Generally, because of limitations in dry storage capability, a decision as to whether the fly ash will be used or waste must be made within 24 hr. by the utility or the fly ash marketing agent [7]. It is more advantageous to an electric utility to sell a higher percentage of its ash, even at low or subsidized price, since this avoids the cost of disposal. In the 60's and 70's this was not too important since the cost of ash disposal was typically less than $ 1.00 per ton. However, due to the more stringent environmental regulations of the late 1970's, the cost of ash disposal has typically escalated to at least the $ 2.00 to 5.00 per ton range and often higher [8]. The Electric Power Research Institute, EPRI, recently estimated that the average cost of disposal of coal ash currently exceeds $10.00/ton. Some utilities currently report disposal costs in excess of $50.00/ton due to limitations and restrictions on landfills in their States [9].

Dry fly ash was the ash that is directly collected from the hopper. The weathered fly ash which has been mixed with brackish water from the river was picked up from the pond where it is often stored for more than 6-12 months. These two types of fly ash were believed to have different characteristics on the properties of fly ash concrete. In this study, the properties of these two fly ashes were studied in order to identify the key parameters influencing the characteristics of fly ash in concrete.

EXPERIMENTAL PROGRAM

Materials

Materials used in this study consisted of standard type I portland cement, siliceous sand passing sieve No 4 (river sand), dry and weathered fly ashes, and water.

Dry and Weathered Fly Ash

Fly ashes generated from the local power plants of the Public Service Electric & Gas Company (PSE&G) in New Jersey can be categorized into two kinds based on different storage conditions, dry and weathered. Dry fly ash was collected from storage silo. Weathered fly ash was collected in a very damp state. Since weathered fly ash was stored in the pond, the fly ash particles tend to set and compact together forming a denser and larger lumps. In this experiment, the weathered fly ash was air-dried for about 1 week, then ground and sieved through sieve No. 50 (0.3 mm.) before mixing with cement.

In this investigation, the following tests were carried out to study the chemical, physical, and mechanical properties of fly ash, cement, and fly ash-cement mortar. These tests evaluate for the chemical composition and particle size distribution of fly ash, setting time, and the compressive strength of fly ash mortar.

Mix Proportions

Table 1 summarizes all the mix proportions used in this study. All samples were cured in saturated lime water. The compressive strength of 2"x2"x2" cube fly ash mortar was tested at ages of 1, 3, 7, 14, 28, 56, 90, and 180 days. The data used in the strength analysis was obtained from the average of three specimens.

Table 1 Mix Proportion of Cement-Fly Ash Mortar by Weight

Series	Sam.	Cem. (g)	Dry FA. (g)	Wea. FA. (g)	River Sand (g)	Water (ml)
	JC	500	-	-	1375	250
	RD10	450	50	-	1375	250
	RD20	400	100	-	1375	250
	RD30	350	150	-	1375	250
	RD40	300	200	-	1375	250
I	RW10	450	-	50	1375	250
	RW20	400	-	100	1375	250
	RW30	350	-	150	1375	250
	RW40	300	-	200	1375	250
	AD10	500	50	-	1375	250
	AD20	500	100	-	1375	250
	AD30	500	150	-	1375	250
II	AD40	500	200	-	1375	250
	AW10	500	-	50	1375	250
	AW20	500	-	100	1375	250
	AW30	500	-	150	1375	250
	AW40	500	-	200	1375	250

Sample designated as "JC" represents the control mortar which only cement was used and had no fly ash at all. Series I or "R" refers to mixes which fly ash was used as cement replacement whereas series II or "A" is for mixes which fly ash was used as additive in addition to cement. Symbols "D" and "W" represent the "dry" and "weathered" condition of the fly ash used.

RESULTS AND DISCUSSIONS

Chemical Composition of Fly Ashes and Cement

Chemical composition of fly ashes and cement were determined by X-Ray Fluorescence [10]. Table 2 shows the chemical composition of fly ashes and cement used in this study. According to ASTM C 618 [14], both fly ashes were classified as Class F fly ash. Dry and weathered fly ash have very little difference in its chemical composition. Dry fly ash has 53.53% of SiO_2 while weathered fly ash has 50.15%. Al_2O_3 content for dry and weathered fly ash is 26.70% and 29.11%, respectively. The calcium oxide content which is believed to affect the reactivity rate is only 1.65% for dry fly ash and 1.70% for the weathered fly ash. In general, it can be concluded that there is almost no variation on the chemical compositions of fly ash as associated with the weathering conditions. Yasuda et al. [15] also indicated the same result that fly ash stored in wet condition in the field for about 3 months was not impaired in quality.

Particle Size Analysis of Dry and Weathered Fly Ashes

For fly ash of particle sizes larger than 75 microns (retaining on 200 sieve) the distribution was determined by wet sieve analysis, for those smaller than 75 microns the distribution was determined by sedimentation process using hydrometer [11].

The particle size distribution of dry and weathered fly ashes are shown in Fig. 1. It can be observed that weathered fly ash has a little more finer particle than the dry fly ash. The extra finer particle was believed to be clay or dust since the weathered ash was in the pond for a long period of time and collected all kinds of contaminants which came with the river. Furthermore, the particle size of fly ash depends a great deal on the location in the pond where ash was collected. The closer to the inflow outlet, the larger is the particle size of fly ash.

Table 2 Chemical Composition of Fly Ashes and Cement

Sample	Chemical Composition (%)								
	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	Na_2O	K_2O	SO_3	Mois
Cement	19.96	8.92	59.33	3.10	2.72	0.43	0.88	2.76	-
Fly Ash (Dry)	53.57	26.70	1.65	0.77	5.08	0.30	1.99	0.70	0.23
Fly Ash (Wea)	50.15	29.11	1.70	0.81	6.12	0.51	1.95	0.10	0.65

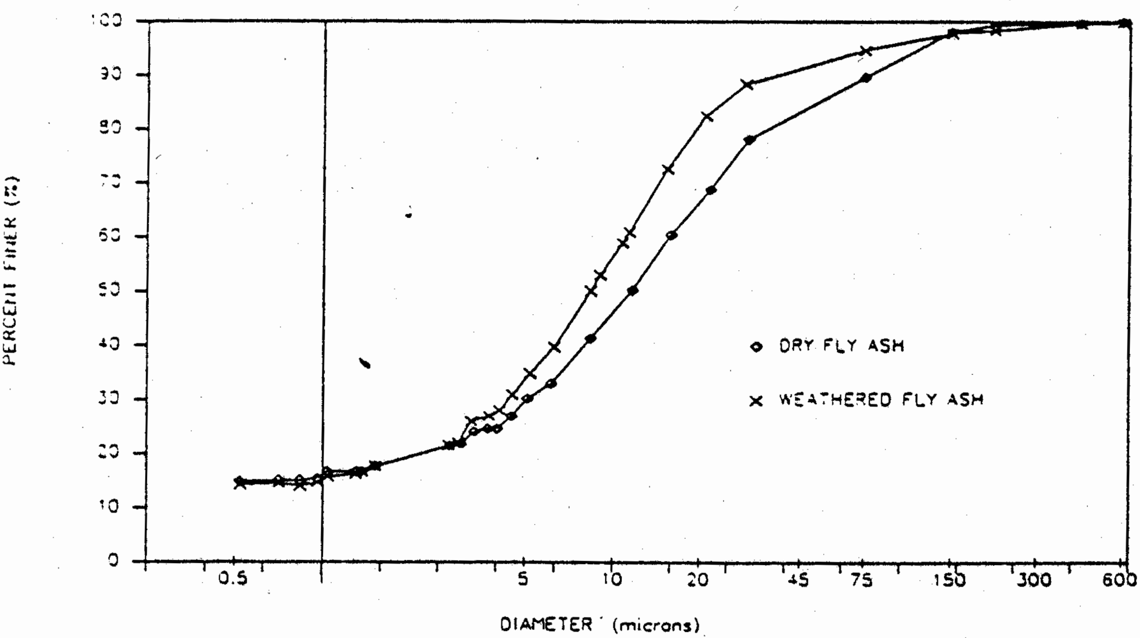

Fig. 1 Particle Size Distribution of Dry and Weathered Fly Ashes

Setting Time

Setting time of cement and cement-fly ash paste were determined by Vicat [12] and Gillmore [13] methods.

Table 3 is the setting time of cement-fly ash paste. Sample RD and RW have the same mix proportion of cement and fly ash as shown in Table 1 except that no sand was used. The initial setting time by Vicat needle or Gillmore needles gives very close results. It seems that the Gillmore needles method gives a little longer setting time than the Vicat needle method.

Considering in term of normal consistency, w/c, the normal consistency is higher with the higher content of fly ash. If we consider in term of water to cementitious ratio, w/(c+fa), it is nearly constant at 28.0 which is the same value for the cement paste.

The results show that the presence of fly ash in the mix increases the setting time. The higher the percentage of fly ash, the longer the setting time is. The works reported by Meinlinger [7], Ravina [16], and Costa and Massazza [17] also showed an increase in setting time with the increase of fly ash in cement. This is due to the Class F fly ash possesses no cementitious material and the presence of fly ash will dilute the concentration of the mix while other factors such as water, temperature, humidity, etc., remain constant.

Table 3 Setting Time of Cement-Fly Ash Paste

Sam. No.	Normal Consistency (%)		Initial Setting		Final Setting	
	W/C	W/(C+FA)	Vicat hr:min	Gillmore hr:min	Vicat hr:min	Gillmore hr:min
CEM.	28:00	28:00	2:20	2:40	5:30	5:30
RD10	30:76	27:69	2:25	2:30	5:55	5:55
RD20	35:00	28:00	2:35	3:00	6:00	6:05
RD40	48:71	29:23	3:35	3:55	7:55	8:00
RW10	31:79	28:61	3:10	3:35	6:20	6:20
RW20	36:15	28:92	4:15	4:30	6:50	7:00
RW40	49:23	29:53	5:35	6:00	>9:00	>9:00

The initial and final setting times of cement paste by Vicat needle are 2 hr 20 min and 5 hr 30 min, respectively. With the Gillmore needles test, the initial and final setting times of cement paste are 2 hr 40 min and 5 hr 30 min, respectively. Both methods seem to agree closely with each other. The use of high percentage of fly ash results in longer setting time. RW20 and RW40 had initial setting time of 4 hr 15 min and 5 hr 35 min, respectively, by Vicat needle and Gillmore needles. These are much longer than the setting time of cement paste. It should also be noted that the final setting time of RW40 is longer than 9 hr which is 3 hr 30 min longer than the cement paste. For the same amount of fly ash in the paste, weathered fly ash prolongs setting time further than the dry fly ash. The initial and final setting time of RD40 are 3 hr 35 min and 7 hr 55 min by Vicat needle while for RW40 are 5 hr 35 min and >9 hr, respectively. This means that the weathered fly ash is less reactive than the dry fly ash.

ASTM C 150 [18] specifies that the initial setting time of standard portland cement type I by Vicat test and Gillmore test be not less than 45 min and 60 min, respectively. For the final setting time, it must not be more than 6 hr 15 min and 10 hr by Vicat and Gillmore tests, respectively. It is crucial that the mix proportion be carefully selected when introducing fly ash in the cement paste since setting time may be the major factor. With high volume use of fly ash in the cement paste, the setting time may be longer than those specified by the ASTM C-150.

<u>Compressive Strength of Fly Ash Mortar</u>

The dry and weathered fly ashes were used in two different approaches: 1) as a cement replacement, and 2) as an additive to the conventional mix. For the first case, the amount of water, sand, and cementitious (cement+fly ash) materials were kept constant. The amount of cement replaced by fly ash varies from 10% to 40% by weight of cementitious materials. For the latter case, fly ash was simply added to the mix in addition to the existing materials used in the cement mortar.

Fly Ash as a Cement Replacement

Tables 4 and 5 show the compressive strength and the percentage compressive strength gained of fly ash mortars. It can be seen that the use of fly ash as a cement replacement reduces the compressive strength of mortar at early ages. This result is the disadvantage of using fly ash as cement replacement on a one-to-one ratio by weight [2,19]. Usually, weathered fly ash lowers the compressive strength more than the dry fly ash for the same amount of fly ash used. After 180 days, the replacement of dry or weathered fly ash up to 30% gives the same compressive strength as the control mortar.

Table 4 Compressive Strength of Dry and Weathered Fly Ash Mortar as a Cement Replacement and as an Additive

Sam. No.	Compressive Strength (psi)							
	1-day	3-day	7-day	14-day	28-day	56-day	90-day	180-day
JC	2144	4303	5252	6109	6884	7320	7448	7918
RD10	1845	4146	5004	5576	6170	6747	7214	7943
RD20	1700	3655	4366	4852	5583	6127	6642	7666
RD30	1375	3288	3932	4839	5668	5980	6805	8178
RD40	1204	2295	2818	3610	4415	4975	6087	7078
RW10	1826	3652	4378	4987	5819	6051	6844	7761
RW20	1439	3180	3699	4158	4599	5432	6432	7680
RW30	1029	2850	2969	3737	4340	5045	6213	7599
RW40	848	1754	2043	2628	3213	3947	4926	5473
AD10	2386	4389	5434	6313	7082	7584	7878	9342
AD20	2444	4286	5776	6845	7283	8134	8670	9768
AD30	2487	4359	5053	6195	7173	8051	8373	9331
AD40	2027	4541	5164	6244	6807	8009	8445	9120
AW10	2318	4469	5297	6255	6902	7675	7870	8819
AW20	2444	4342	5302	6410	7020	8055	8504	9463
AW30	2401	4790	5286	6104	6877	8600	9544	10554
AW40	2187	4613	5348	6291	6895	8579	9481	10158

Replacement of Cement with Dry Fly Ash

The effect of replacing cement with dry fly ash on the strength of mortar is shown in Fig. 2. It shows that RD40 has the lowest strength at all ages. Its strength varies from 1,204 psi. at 1 day to 7,078 psi at 180 days or 56% to 89% of the control strength. The use of high volume of fly ash as cement replacement, i.e. 40%, resulted to a low early strength which was only about 50% to 60% and gradually increased with ages.

Fig. 3 is the relationship between the compressive strength of the dry fly ash mortar and the dry fly ash/cement ratio. At early age, the compressive strength of fly ash mortar reduces with the increasing of fly ash/cement ratio. After 90 days, fly ash starts showing its strength contribution and the optimum fly ash content is between 20 to 30% by weight of cementitious material.

Replacement of Cement with Weathered Fly Ash

Fig. 4 shows that the effect of weathered fly ash on the strength of mortar is almost the same as the dry fly ash except that the weathered fly ash gives a lower compressive strength when the same amount of fly ash was used as cement replacement. The replacement of 40% by weight of cementitious materials with the weathered fly ash gives the strength of 40% at 1-day and 69% at 180-day when compared with the control mortar. The strength of all weathered fly ash mortars gives lower compressive strength than the control strength at all ages up to 180 days. In Fig. 5, the compressive strength of weathered fly ash and weathered fly ash/cement ratio shows no optimum of fly ash when used in cement.

Table 5 Percentage Compressive Strength of Dry and Weathered Fly Ash Mortar as a Replacement and as an Additive

Sam. No.	Percentage Compressive Strength							
	1-day	3-day	7-day	14-day	28-day	56-day	90-day	180-day
JC	100	100	100	100	100	100	100	100
RD10	86	96	95	91	90	92	97	100
RD20	79	85	83	79	81	84	89	97
RD30	64	76	75	79	82	82	91	103
RD40	56	53	54	59	64	68	82	89
RW10	85	85	83	82	85	83	92	98
RW20	67	74	70	68	67	74	86	97
RW30	48	66	57	61	63	69	83	96
RW40	40	41	39	43	47	54	66	69
AD10	111	102	103	103	103	104	106	118
AD20	114	100	110	112	106	111	116	123
AD30	116	101	96	101	104	110	112	118
AD40	95	106	98	102	99	109	113	115
AW10	108	104	101	102	100	105	106	111
AW20	114	101	101	105	102	110	114	120
AW30	112	111	101	100	100	117	128	133
AW40	102	107	102	103	100	117	127	128

The results on the compressive strength of this study do not agree with those reported by Yasuda et al. [15]. Their results showed that the strength of mortar or concrete contained wet-stored fly ash increased. They explained that weathered fly ash may raise the adhesion capability between fly ash and cement particles due to slight roughness of fly ash particle surface, and by the increase in activation of fly ash particles. Finally, they concluded that fly ash dumped at an ash disposal area for 7 years had never deteriorated. This may be true if one considers the chemical composition of the dry and weathered fly ash presented in Table 2.

However, the authors found that apparent particle size distribution tends to change with damped storage condition

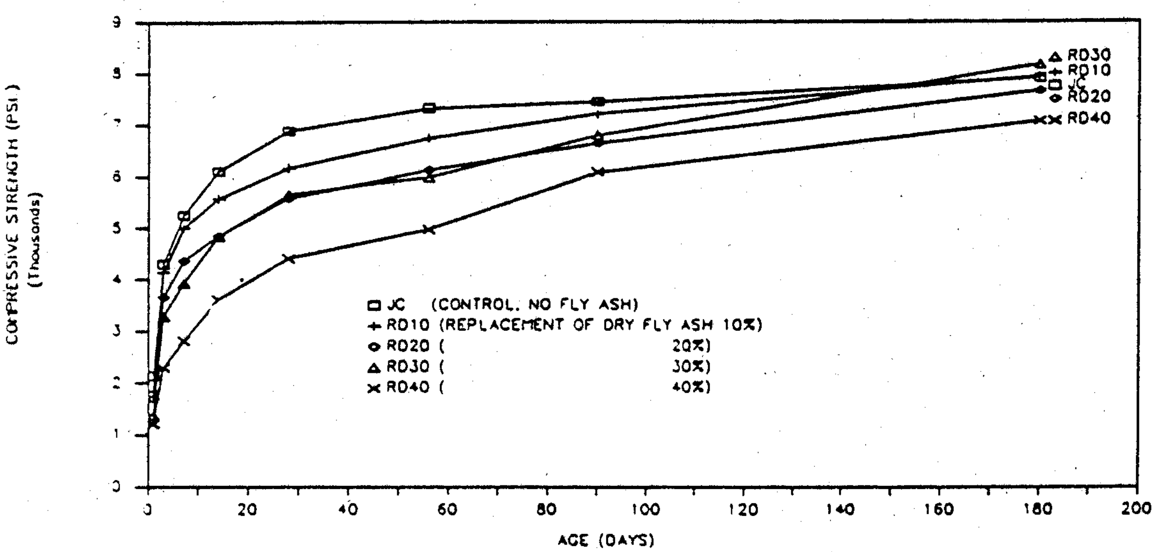

Fig. 2 Effect of Cement Replacement with Dry Fly Ash on the Strength of Mortar

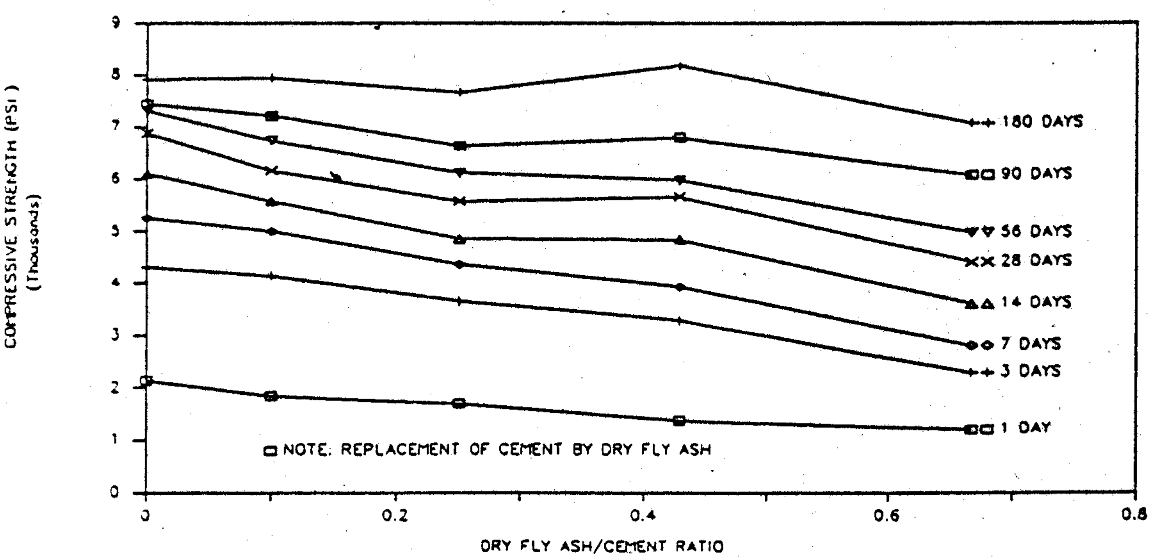

Fig. 3 Relationship Between Compressive Strength of the Dry Fly Ash Mortar and the Fly Ash/Cement Ratio

Many investigators concluded that fly ashes with higher percentage of finer particles gave higher strengths [20,21,22,23]. Although the finer particle size of weathered fly ash is higher than the dry fly ash, the use of weathered fly ash results in a lower compressive strength than the use of dry fly ash with the same quantity. The reverse result shown in this study may be due to the impurities of the weathered fly ash. An investigation was carried out by soaking both the dry and the weathered fly ashes in tapped water. The results indicated that the soaked water from the weathered fly ash is much darker than the one from the dry fly ash. It is believed that the weathered fly ash may have gather some additional contaminants such as clay and dust while sitting in the storage pond with brackish water from the river. According to Kiattikomol and Jaturapitakkul [24] the compressive strength of concrete can be reduced approximately by 15% with the presence of 3% of clay by weight of sand. Another reason may be that the crystalline phase in weathered fly ash does not dissolve to a glassy phase as expected during the ponding periods. These attributed factors may be the cause of the lower compressive strength of the weathered fly ash mortar than the one with dry fly ash.

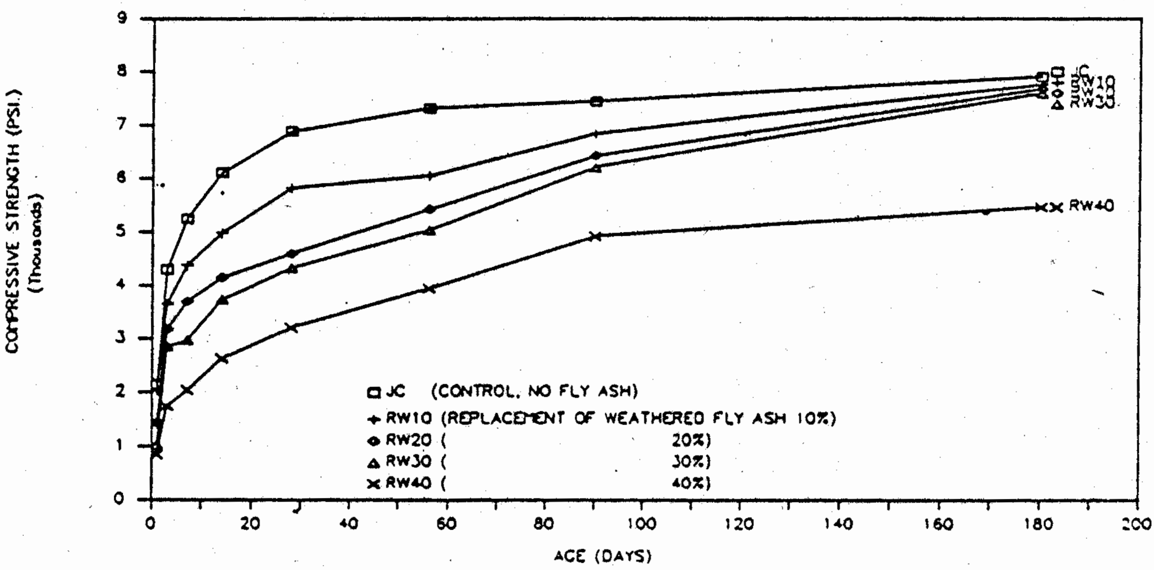

Fig. 4 Effect of Cement Replacement with Weathered Fly Ash on the Strength of Mortar

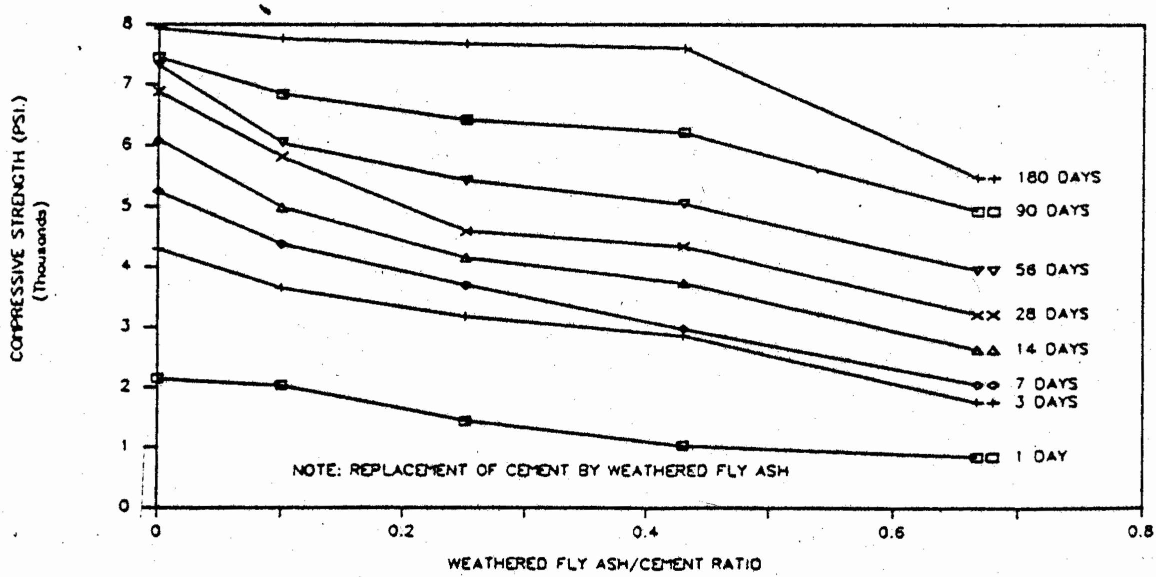

Fig. 5 Relationship Between Compressive Strength of the Weathered Fly Ash Mortar and the Fly Ash/Cement Ratio

Fly Ash as an Additive

Generally, the addition of fly ash up to 40% by weight of cement results in a higher compressive strength of mortar at all ages. Berry and Malhotra [25] reported that the addition of dry fly ash generally increased the strength of concrete at all ages. The addition of very high volume of fly ash (more than 30%) causes lumps in the mix and sometimes reduces the compressive strength.

Addition of Dry Fly Ash

The effect of adding fly ash on the strength of mortar is shown in Fig. 6. Addition of dry fly ash generally reduces the workability of mortar but increases the compressive strength. It can be seen that the compressive strength tends to increase with the age of fly ash mortar. The addition of 10% dry fly ash by weight of cement increases the compressive strength from 7,082 psi at 28 days to 9,342 psi at 180 days or from 103% to 118% of the control strength, respectively. The addition of 20% fly ash produces the highest compressive strength (See Fig. 7). For this optimum percentage, the compressive strength varied from 2,444 psi at 1-day to 9,768 psi at 180-day or 114% to 123% of the control strength.

Addition of Weathered Fly Ash

In Fig. 8, the addition of weathered fly ash results in higher compressive strength than the control mortar. The compressive strength of AW30 varied from 2,401 psi at 1 day to 10,554 psi at 180 days or 112% to 133% of the control strength. The increase of compressive strength is small up to the age of 28 days but later shows a more pronounced effect at 180 days. At early age, the addition of fly ash does not effect the strength of mortar. In Fig. 9, the fly ash-cement ratio does not have any effect on the strength of fly ash mortar until the age of 28 days. After that, an increasing trend was observed. The addition of 30% of weathered fly ash gives the highest compressive strength.

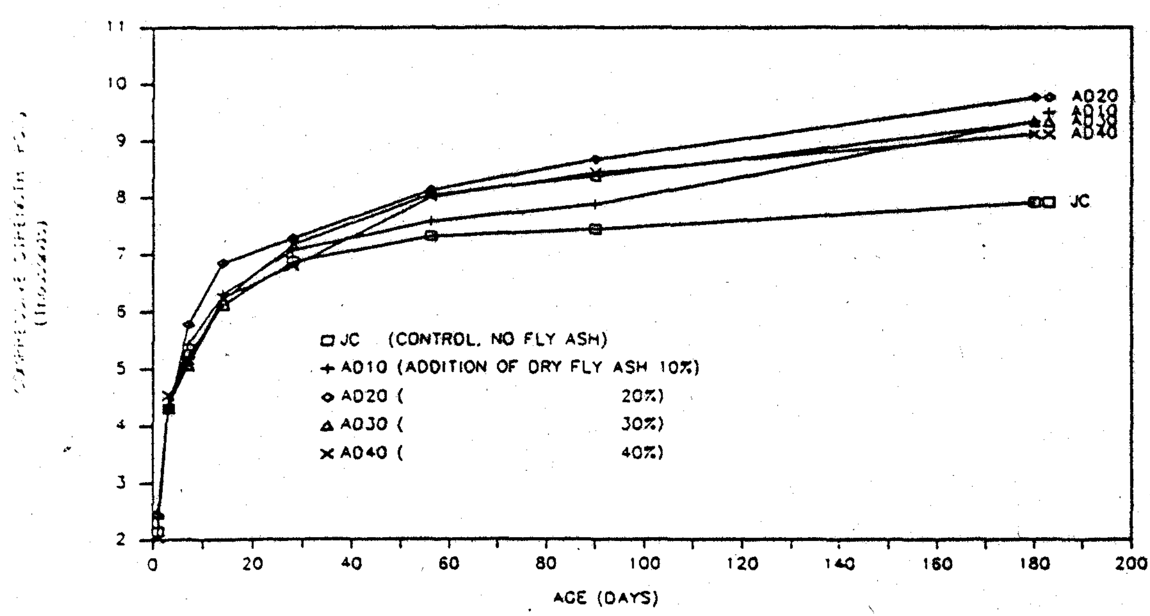

Fig. 6 Effect of Addition of Dry Fly Ash on the Strength of Mortar

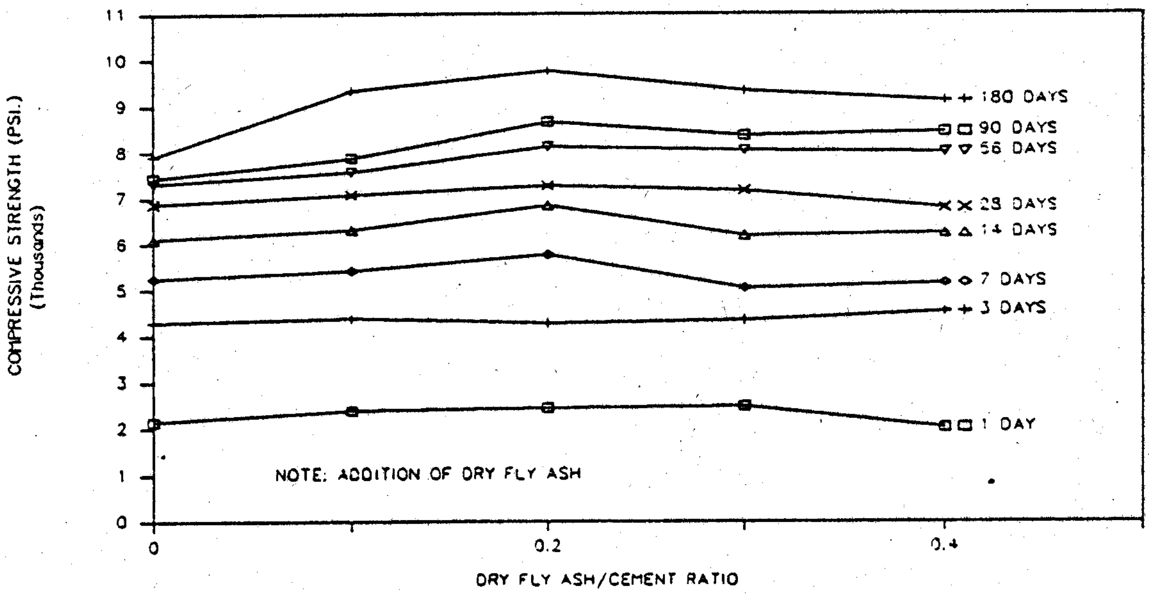

Fig. 7 Relationship Between Compressive Strength of (Addition) Dry Fly Ash Mortar and Fly Ash/Cement Ratio

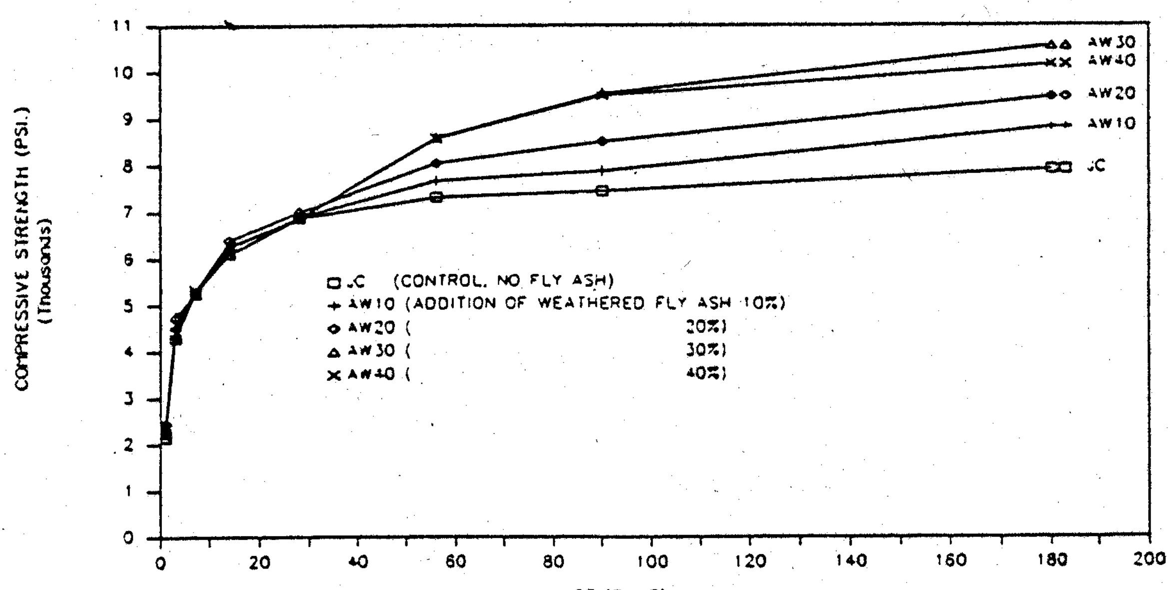

Fig. 8 Effect of (Addition) Weathered Fly Ash on the Strength of Mortar

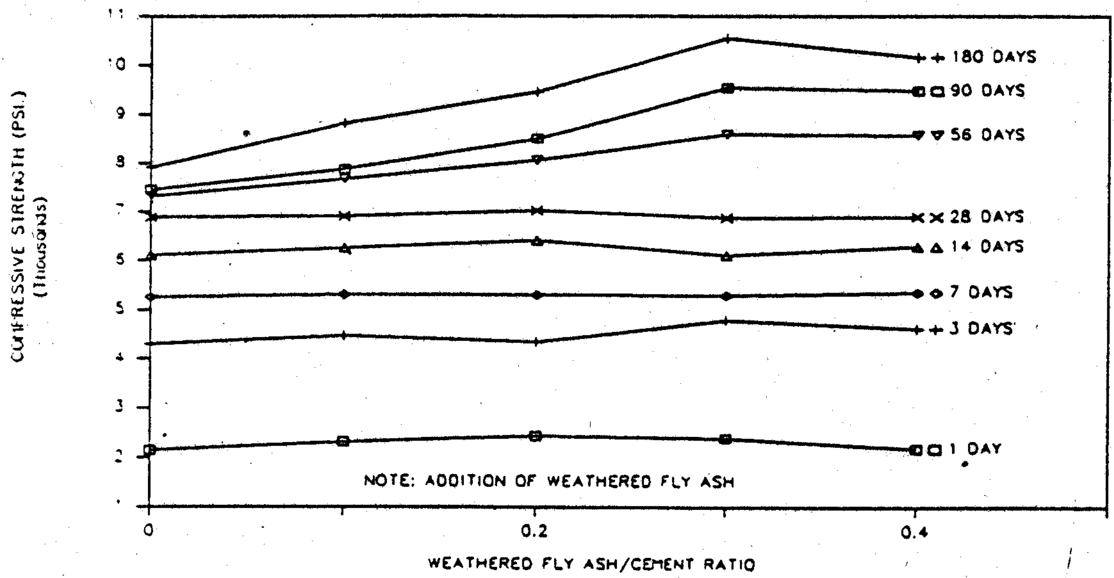

Fig. 9 Relationship Between Compressive Strength of (Addition) Weathered Fly Ash Mortar and Fly Ash/Cement Ratio

CONCLUSIONS

1. There is almost no variation on the chemical composition of fly ashes as associated with weathering process.

2. The presence of fly ash prolongs the setting time. With the same quantity of fly ash used in the cement-fly ash paste, weathered fly ash prolongs longer setting time than the dry fly ash.

3. As a cement replacement, weathered fly ash mortar exhibits lower compressive strength than the dry fly ash. After 180 days, the replacement of dry fly ash or weathered fly ash up to 30% gives the same compressive strength as the control mortar.

4. The addition of fly ash to concrete and mortar gives higher compressive strength than the control mortar. The optimum addition of dry fly ash is at about 20% of cement and about 30% for the weathered fly ash.

5. The major differences between the dry and the weathered fly ashes are probably at the presence of extraneous contaminants and the potential variation of particle size and its distribution.

ACKNOWLEDGEMENTS

This research was supported by grants from the Public Service Electric and Gas Company of New Jersey (Program Director: Mr. Jeffrey Hynds) and the U.S. Department of Energy (DOE), grant No. DOE-DE-FG-22-90PC90299 (Program Director: Mr. Jerry L. Harness). Their financial supports are gratefully acknowledged here.

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