การศึกษาเถ้าถ่านหินที่มีอนุภาคต่างขนาดในงานคอนกรีต
FRACTIONATED FLY ASH CONCRETE

ชัย จาตุรพิทักษ์กุล
CHAI JATURAPITAKKUL
Lecturer
Department of Civil Engineering
King Mongkut's Institute of Technology Thonburi
Bangmod, Rasburana, Bangkok, 10140, THAILAND

เมธี เวชารัตนา
METHI WECHARATANA
Professor

JOHN W. LISKOWITZ
Professor

Department of Civil and Environmental Engineering
New Jersey Institute of Technology
Newark, New Jersey, 07102, USA.

บทคัดย่อ

เถ้าถ่านหินเกิดจากการเผาถ่านหินเพื่อใช้ในการผลิตกระแสไฟฟ้า คุณสมบัติที่สำคัญอย่างหนึ่งของเถ้าถ่านหินในการเพิ่มประสิทธิภาพของคอนกรีต คือคุณสมบัติทางพอซโซลานิค เถ้าถ่านหินที่ได้จากการเผาถ่านหิน มักมีคุณสมบัติไม่แน่นอนขึ้นอยู่กับปัจจัยหลายอย่าง เช่น

ชนิดของเตาเผา ชนิดของถ่านหิน ชนิดของเครื่องบดถ่านหิน หรือความสามารถของเครื่องรวบรวมเถ้าถ่านหิน ในปัจจุบัน เถ้าถ่านหินที่ผลิตได้ในแต่ละปีนั้นมีจำนวนมากขึ้น แต่พื้นที่ที่ใช้ทิ้งเถ้าถ่านหินเหล่านี้มีจำกัด และเหลือน้อยลงทุกที กอร์ปกับข้อจำกัด และกฎระเบียบที่เข้มงวดขึ้นทางด้านสิ่งแวดล้อม ทำให้ค่าใช้จ่ายในการกำจัดเถ้าถ่านหินสูงขึ้นอย่างมาก วิธีที่ดีที่สุดของการกำจัดเถ้าถ่านหินก็คือการนำเถ้าถ่านหินเหล่านี้มาใช้ประโยชน์ในงานอุตสาหกรรม

งานวิจัยนี้เลือกเถ้าถ่านหิน 2 ชนิดคือ ชนิดที่เรียกว่า เผาโดยระบบแห้ง กับที่เผาโดยระบบเปียก เถ้าถ่านหินทั้ง 2 ชนิดนี้ จะนำไปแยกอนุภาคออกตามขนาดเล็ก-ใหญ่ อนุภาคขนาดเล็กมีขนาดของอนุภาคราว 1.85 ไมโครเมตร ส่วนอนุภาคขนาดใหญ่ จะมีขนาดของอนุภาคประมาณ 40 ไมโครเมตร จากนั้นทำการตรวจสอบคุณสมบัติทางกายภาพและเคมีของเถ้าถ่านหินที่แยกอนุภาคแล้ว เพื่อนำมาเปรียบเทียบกับเถ้าถ่านหินที่ไม่ได้แยกอนุภาค นอกจากคุณสมบัติทางด้านกายภาพและเคมีของเถ้าถ่านหินแล้ว เถ้าถ่านหิน 35 เปอร์เซนต์โดยน้ำหนักปูนซีเมนต์ หรือ 25.9 เปอร์เซนต์โดยน้ำหนักปูนซีเมนต์บวกกับน้ำหนักของเถ้าถ่านหิน จะใช้แทนปูนซีเมนต์ในการผสมคอนกรีตเพื่อศึกษาคุณสมบัติของกำลังอัดของเถ้าถ่านหินคอนกรีต การทดสอบกำลังอัดกระทำที่อายุ 1, 3, 7, 14, 28, 56, 90, และ 180 วัน

จากการทดลองพบว่า ส่วนประกอบทางด้านเคมีของเถ้าถ่านหินขนาดเล็กหรือใหญ่เปลี่ยนแปลงเพียงเล็กน้อยเท่านั้น อนุภาคที่เล็กละเอียดของเถ้าถ่านหินจะทำปฏิกิริยาได้เร็วกว่าอนุภาคขนาดใหญ่กว่า โดยเฉพาะอย่างยิ่งเมื่อใช้อนุภาคของเถ้าถ่านหินขนาดเล็กที่สุด จะให้กำลังอัดของคอนกรีตที่เท่ากันหรือสูงกว่าเมื่อเปรียบเทียบกับคอนกรีตที่ไม่ได้ใช้เถ้าถ่านหินที่อายุ 28 วัน สำหรับการใช้เถ้าถ่านหินที่มีขนาดอนุภาคที่ใหญ่ๆนั้น พบว่ากำลังอัดของคอนกรีตที่อายุ 180 วัน มีค่าเพียง 85 เปอร์เซนต์ของคอนกรีตที่ไม่ได้ใช้เถ้าถ่านหิน

SUMMARY

Fly ash is commonly known to have pozzolanic behavior which can enhance the property of concrete. Since fly ash is a by-product from coal-burning power generation process, it is often found to be inconsistent and varies widely depending on the type of boiler, the type of coal, pulverizing equipment, and the removal efficiency of the air pollution control devices. With large quantity of fly ash generated annually worldwide associated with the shortage of landfill due to environmental concerns the disposal cost of all waste has escalated rapidly in recent years. The need to seek better utilization of industrial by-products such as fly ash is then critical.

In this study, two types of fly ash, dry and wet bottom ashes, were used. Fly ashes were separated into different particle sizes. The particle size distributions of fractionated fly ashes varied from a very small mean diameter of less than 1.85 micron, to the largest of about 40 microns. Physical and chemical properties of the fractionated fly ashes were tested and compared with the original feed fly ashes, fly ash received from the utility's silo. The effect of fractionated fly ashes on the strength of concrete were studied when used as a 35 percent cement replacement by weight of cement or 25.9 percent by weight of cementitious materials. Compressive strengths of the fractionated fly ash concrete were tested at the age 1, 3, 7, 14, 28, 56, 90, and 180 days.

The results show that the chemical composition of fractionated fly ash changes slightly when fly ash is separated into different particle sizes. From the same type of fly ash, the finer the particle the higher is the specific gravity. The smaller fly ash particle has a faster reactivity rate than the coarser one. With the very small particle sizes, the compressive strength of fly ash concrete is equal to or higher than the control concrete before the age of 28 days. With the very large particle sizes, the fly ash concrete reaches only 85 percent of the control concrete strength at the age of 180 days.

INTRODUCTION

Fly ash is a by-product of coal burning thermal power plants. During the combustion process, about 75 or 80% of fly ash will fly out of the combustion chamber. Some of the ashes are withdrawn from the furnace as bottom and boiler slag [1]. In 1988 approximately 84 million tons of coal ash were produced in the U.S. in the form of fly ash, bottom ash, and boiler slag. Slightly more than a quarter of the combined production of these by-products was used, while the remaining three-quarter went to disposal areas [2]. Shortage of landfill due to environmental concerns has resulted to the escalation of disposal cost of all waste. The Environmental Protection Agency (EPA) estimated in 1987 that the total cost of waste disposal at coal fired plants ranged from $11.00 to $20.00/ton for fly ash and bottom ash [3].

Instead of regarded as a waste of nuisance value, fly ash should be considered as a pozzolanic material with potential to use in cement and construction industry. It was the intensive studies undertaken by Davis et al. [4] that paved the way for the use of fly ash in concrete. Since then, many investigations were conducted to study the use of fly ash in concrete. Fly ash has a complex characteristic, differing in fineness, morphology, mineralogical composition, and glass content. These characteristics of fly ashes tend to affect the hydration process, the hardening and the microstructural development of the blended cement paste system [5].

Lane and Best [6] summarized the advantage and disadvantage of fly ash for use in the concrete industry. The advantages are: a) improved workability, b) reduced segregation, c) reduce bleeding, d) reduce heat evolution, e) reduce drying shrinkage, f) increased resistance to sulfates, g) increase ultimate tensile and compressive strength, and h) reduced permeability.

The disadvantages when fly ash replaced cement on a one-to-one ratio by weight are: a) lower early strength, b) lower resistance to freezing and thawing, and c) increased air-entraining admixture requirement for equal air content.

Experimental data reported so far seems to indicate that the contribution of fly ash to enhance the quality of concrete is not a constant value determined solely by the physical and chemical characteristics of the ash but rather it varies in different concretes [7]. It is difficult to predict concrete performance through characterization of fly ashes alone. Therefore, fly ash acceptability with regard to workability, strength development, and durability must be investigated through trial mixtures of concrete containing fly ash [8].

This research work is emphasized on the study of fractionated fly ash concrete. Fly ash is separated into different particle sizes. Each fraction of fly ash has shorter range of particle size distribution than original feed fly ash, fly ash as received from storage silo of a utility. The particle size distributions of fractionated fly ashes varies from a very small mean diameter of less than 1.85 micron, to a very large mean diameter of about 40 microns. Due to its short range of the size distribution, each fractionated fly ash gives a more unique relation of its pozzolanic activity than the original feed fly ash which has a wider range of particle size distribution. Physical and chemical composition of fractionated fly ashes and the original feed fly ashes are examined. Concrete with 35 percent by weight of cement replaced by fractionated fly ash is cast and tested at different ages. Compressive strengths of fractionated fly ash concrete are investigated and compared with the control concrete.

EXPERIMENTAL PROGRAM

Materials

Materials used in this study consist of standard type 1 Portland cement, fly ashes, siliceous sand, crushed basalt as coarse aggregate, and water.

Fly ashes from two types of coal-fired boiler were investigated in this study. The first was the dry bottom boiler with direct fired burns located on opposite walls. The second type was a wet bottom boiler. The main difference of these two boilers is that the dry bottom boiler is designed to have flame being below the fluid temperature of the coal ash, i.e. 2600^{o}F, while the wet bottom boiler generates flame higher than the fluid temperature of the coal ash [9].

Two tons of dry and wet bottom fly ashes were collected from the utility and sent for separation into different particle sizes using the Micro-Sizer Air Classifying System. Seven particle size distributions were fractionated from each fly ash. The cut range of these particle sizes were 0-5 um, 0-10 um, 0-15 um, 0-20 um, 0-30 um, 0-44 um, and the original feed fly ash.

Particle Size Analysis

The particle size distribution of fly ash larger than 75 microns was determined by wet sieve analysis [10] while the distribution of particle size smaller than 75 microns was determined by the Microtrac, a laser-based particle sizer. The particle size distribution of fractionated fly ashes from the dry and wet bottom boilers are shown in Figs. 1 and 2., respectively. The curve for the original feed fly ash is not as steep as others since it has a wider range of size distribution.

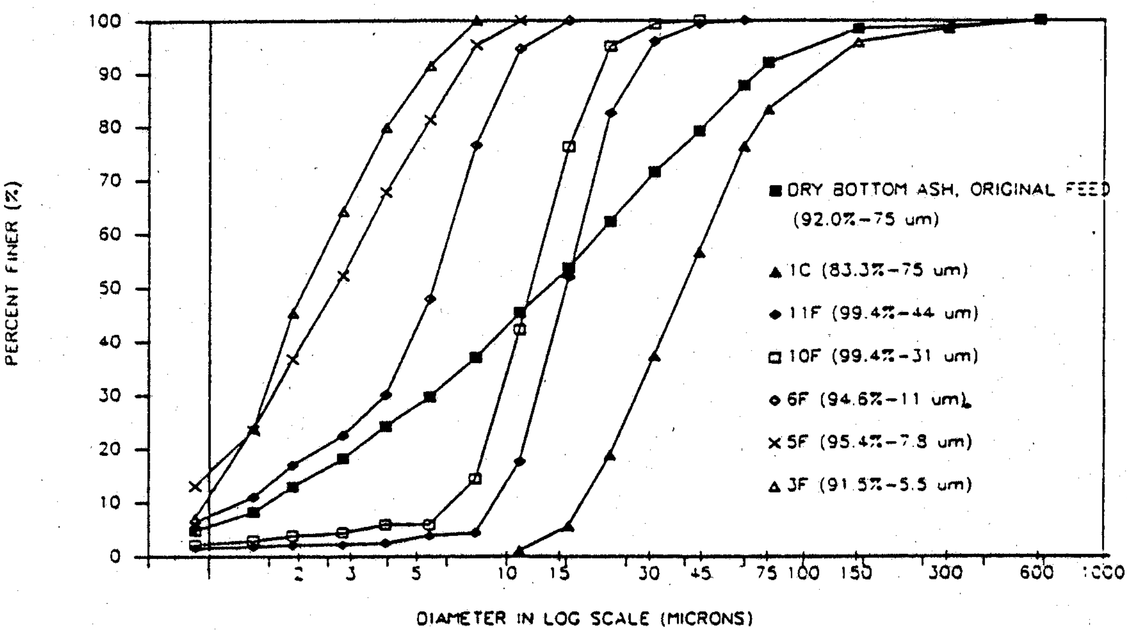

Fig. 1 Particle Sizes Distribution of Dry Bottom Ash

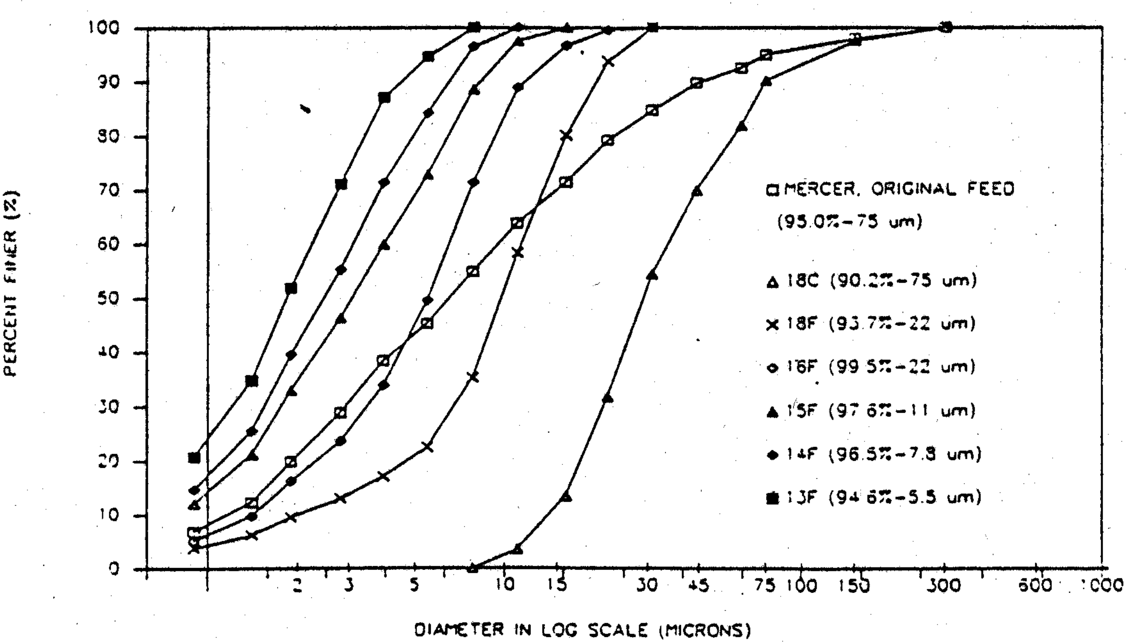

Fig. 2 Particle Sizes Distribution of Wet Bottom Fly Ash

Chemical Composition of Fractionated Fly Ash and Cement

Chemical composition of fractionated fly ashes and cement were determined by X-Ray Fluorescence [11]. The chemical composition of fractionated fly ashes and cement are presented in Table 1.

Table 1. Chemical Composition of Fly Ash and Cement

	Chemical Composition (%)								
Sam.	LOI.	SO_3	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	Na_2O
CEM.	0.73	2.53	20.07	8.84	1.41	60.14	0.86	2.49	0.28
3F	4.97	1.69	49.89	26.94	5.43	2.99	1.76	0.99	0.33
5F	4.10	1.53	50.27	26.74	5.30	2.95	1.74	0.93	0.33
6F	3.12	1.09	51.40	26.54	4.91	2.72	1.71	0.74	0.31
10F	2.52	0.72	51.98	26.23	4.44	2.28	1.60	0.54	0.29
11F	2.04	0.53	51.27	26.28	4.42	2.02	1.55	0.49	0.26
1C	1.46	0.39	53.01	26.50	5.66	1.90	1.61	0.56	0.24
DRY	2.75	0.98	52.25	26.72	5.43	2.41	1.67	0.69	0.28
13F	2.67	3.81	38.93	24.91	12.89	6.85	2.10	1.55	1.31
14F	1.94	3.47	39.72	25.08	13.02	6.71	2.11	1.50	1.31
15F	1.88	3.33	40.25	25.02	13.12	6.60	2.11	1.47	1.30
16F	2.06	3.05	40.65	24.92	13.26	6.55	2.09	1.41	1.26
18F	1.94	2.94	41.56	24.47	14.21	6.58	2.01	1.40	1.17
18C	2.55	2.40	43.25	23.31	17.19	7.38	2.00	1.30	0.88
WET	2.05	3.13	41.54	24.74	14.83	6.89	2.07	1.43	1.17

Fineness of Fly Ash

The fineness of fly ash was determined by two methods; the Blaine air permeability [12] and the 45 um. (No. 325) sieve [13]. The results on the fineness of fractionated fly ash of both dry and wet bottom ashes are shown in Table 2.

Mix Proportions of Fractionated Fly Ash Concrete

The fractionated fly ashes from dry and wet bottom fly ash were used as a cement replacement of 35% by weight of cement or 25.9% by weight of cementitious materials (cement+fly ash). The water cementitious ratio was kept constant at 0.41. The control concrete, concrete without any fly ash, having the same mix proportion and water cementitious ratio was also mixed and used as reference. No admixture or any kind of chemical admixture was used in this experiment except standard Portland cement type I, fly ash, sand, coarse aggregate, and water. The mix proportions used are shown in Table 3. The 3"x6" cylinders were cast and cured in saturated lime water prior to testing. The compressive strength of samples was tested at the age of 1, 3, 7, 14, 28, 56, 90, and 180 days. The compression tests were conducted using an MTS closed-loop testing machine with a loading rate of $1x10^{-4}$ in/second.

Table 2. Fineness of Cement and Fractionated Fly Ashes
Cement: Portland Cement Type I
Fly Ash: Dry and Wet Bottom Ash

Sam. No.	Specific Gravity g/cm^3	Fineness Retained 45 um. (%)	Blaine (cm^2/g.)	Mean Diameter (um)
CEM	3.122	-	3815	-
3F	2.535	0	7844	2.11
5F	2.529	0	6919	2.66
6F	2.488	0	4478	5.66
10F	2.424	0	2028	12.12
11F	2.400	1.0	1744	15.69
1C	2.279	42.0	1079	39.45
DRY	2.343	20.0	3235	13.73
13F	2.748	0	11241	1.84
14F	2.729	0	9106	2.50
15F	2.641	0	7471	3.09
16F	2.609	0	5171	5.54
18F	2.512	0	3216	9.84
18C	2.416	29.0	1760	29.25
WET	2.500	10.0	5017	6.41

Table 3. Mix Proportion of Fractionated Fly Ash Concrete

Ingredients	CHM (Control) (kg/m^3)	Fly Ash Sam. (kg/m^3)
Portland Cement Type I	475	352
Fly Ash (Dry or Wet Bottom Ash)	-	123
River Sand	704	704
Aggregate Max. Size 3/8", Basalt	1056	1056
Water	197 l.	197 l.
Water/(Cement+Fly Ash)	0.414	0.414

Note that "CHM" represents the control concrete mix.

Slump Test of Fractionated Fly Ash Concrete

Slump test [14] has been used to check the workability of fresh fractionated fly ash concrete. The results of the slump test in this study are presented in Table 4.

Table 4 Slump Test of Fractionated Fly Ash Concrete

Sample	Slump (cm)	Sample	Slump (cm)
3FC35	1.7	13FC35	1.6
5FC35	2.7	14FC35	2.5
6FC35	3.0	15FC35	2.7
10FC35	3.5	16FC35	2.9
11FC35	3.5	18FC35	3.5
1CC35	4.0	18CC35	3.5
CHO35	3.5	CMO35	2.5
CHM	2.0		

CHM refers to the control concrete sample. The 3FC35 sample represents the fractionated fly ash concrete using the 3F fly ash as a 35 percent cement replacement by weight of cement. So 6FC35 generally refers to the fractionated fly ash concrete having the 6F fly ash as a 35 percent cement replacement and so on. CHO35 is the sample from the original feed of dry fly ash while CMO35 is the sample from the original feed of the wet bottom ash.

RESULTS AND DISCUSSIONS

Particle Size Distribution of Fly Ash

From the original feed, each type of fly ash was fractionated into seven ranges. As shown in Figs. 1 and 2, the particle size of fly ash varied from 0-5.5 um to 0-44 um. In case of the 3F fly ash, 3F (91.5%-5.5 um) means that 91.5% of the fly ash particles are smaller than 5.5 um. For the dry bottom ash, 3F is the finest while 1C is the coarsest. For wet bottom ash, 13F is the finest with 18C as the coarsest. The original feed of the wet bottom fly ash was found to be much finer than the original feed of dry bottom ash.

The color of the fractionated fly ashes from fine to coarse varied from light gray to dark gray while for the wet bottom ash the color changed from light brown to dark brown. This same result on the change of color was also reported by Yasuda, Niimura, and Iizawa [15].

Chemical Composition of Fly Ash

Both types of fly ash used in this study were classified as Class F fly ash according to ASTM C 618 [16] since the total oxide of SiO_2 + Al_2O_3 + Fe_2O_3 are higher than 70%. Most of the fractionated fly ashes have some slight variation in the oxide composition when the particle sizes changed. It has been reported that separation of Class F with high calcium fly ash into size fraction does not reveal major chemical morphological or mineralogical speciation between particles [17]. The SiO_2 content tends to be lower when the particle size is larger. The difference of chemical compositions of the two fly ashes are SiO_2, Fe_2O_3, and CaO content. Samples of the dry bottom ash has a richer content of about 10% of SiO_2 than those from the wet bottom ash. The CaO content of the dry bottom ash varies from 1.90% to 2.99%, while for wet bottom ash, the variation is from 6.55% to 7.38%. Fe_2O_3 content of wet bottom ash is two times higher than that of the dry bottom ash. The highest concentration of Fe_2O_3 of each type of fly ashes is in the coarsest particle sizes, i.e., 1C and 18C.

It is interesting to note that after fly ash was fractionated into different sizes, loss on ignition (LOI) of the finest particle is the highest. The LOI content gradually decreases as the particle size increases. The coarser size of fly ash often has lower LOI content than the raw fly ash [18]. Ravina also reported the same behavior that the finest particle of fly ashes has the highest LOI values [19]. The results obtained from Ukita, Shigematsu, and Ishii [20] also showed that the chemical composition did not changed when the mean diameter of fly ash changed from 17.6 micron to 3.3 micron while LOI increased from 2.78 to 4.37. These results are in conflict with the report of ACI 226 Committee [8] and of Sheu, Quo, and Kuo [21] which stated that the coarse fraction usually contains a higher proportion of carbon than the fine fraction.

Fineness Characteristics

There are generally two methods to measure the fineness of fly ash. The first is by determining the residue on the 45 um (No. 325) sieve. The second method is the surface area measurement by air permeability test or Blaine fineness. Opinions differ as to whether sieve residue or surface area are better indicator of fly ash fineness [22]. In the United States, the fineness of fly ash is specified by the residue on the 45 um sieve only. Ravina [19] found that pozzolanic activity is better indicated by specific surface area measurements but Lane and Best [6] argued that the 45 micron sieve residue is a more consistent indicator than the surface area.

The fineness of fly ash both by wet sieve analysis and by Blaine fineness together with the specific gravity of fly ashes are shown in Table 2. Mean diameter, the diameter of which 50 percent of particles are larger than this size, is also presented in this table. According to ASTM C 618 [16], fractionated fly ash "1C" is the only sample that fails to meet the fineness requirement. By using the sieve No. 325, the fractionated fly ash samples 3F, 5F, 6F, 10F, 13F, 14F, 15F, 16F and 18F will have the same fineness since all of them have zero value retained on this sieve.

It can be noted that the finer the particle size of fractionated fly ash, the higher the specific gravity and the Blaine fineness are. Density of fly ash from different plants varied from 1.97 to 2.89 g/cm^3 but normally ranges between about 2.2 to 2.7 g/cm^3 [6]. Work done by Mclaren and Digiolia [23] reported that Class F fly ash had a mean specific gravity value of 2.40. The specific gravity of fractionated fly ash varies from 2.279 for the coarsest fly ash to 2.535 for the finest fly ash of the dry bottom fly ash and from 2.216 for the coarsest to 2.748 for the finest of the wet bottom fly ash. The Blaine fineness is highest in the finest sample, 13F, which is 11241 cm^2/g. Fig. 3 shows the relationship between the Blaine fineness and mean diameter of fly ash. The relation can be expressed as:

$$\textbf{Blain fineness} = 15818 * (\textbf{mean diameter})^{-0.7074} \textbf{ with } R^2 = 0.9396$$

It should be noted that this relationship is derived from the sample of dry and wet bottom ashes of this study. The Blaine fineness increases with the inverse of the mean diameter. The result presented here also confirms with those reported by Aitcin et al. [24]. They showed that if the average diameters, D50, of fly ash are smaller, the surface area of the fly ash will be larger than those with larger average diameters. The specific gravity of fractionated fly ash increases with the decrease of the particle size.

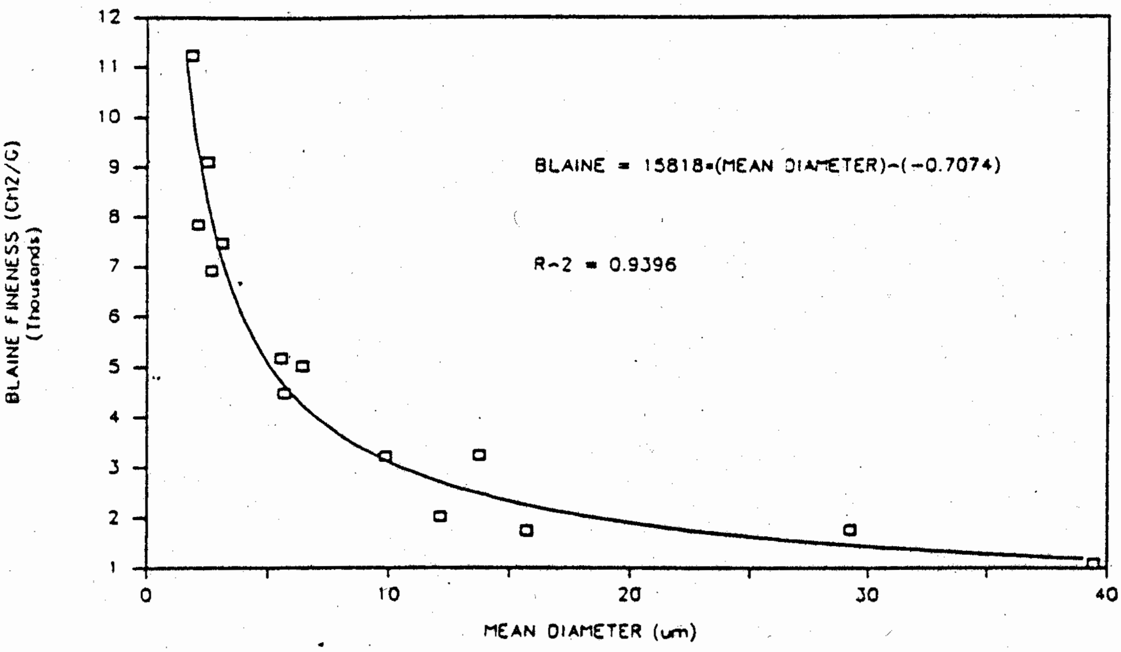

Fig. 3 Relation between Blain Fineness and Mean Diameter (D50) of Fly Ashes

Workability of Fractionated Fly Ash Concrete

Incorporation of fly ash in concrete often improves workability and thereby reduces the water requirement with respect to conventional concretes [6,8,25]. The slump is usually higher when fly ash is used [20]. The results from this experiment show that only the finest fly ash reduces the workability of fresh concrete while other sizes of fly ash behave otherwise. Since the weight of fly ash was kept constant, it is the finer particle of fly ash that has more surface area and thus needs more water to maintain the same workability as the coarser fly ash. The finest fly ash concrete samples of dry and wet bottom ash, 3FC35 and 13FC35, are less workable than that of the control concrete which has a slump of about 2 cm. The slump of fly ash concrete from the original feed fly ashes is slightly higher than the control mix. For the same original feed fly ashes, sample from the dry bottom ash, CHO35, is more workable than those from the wet bottom ash, CMO35. This may be due to the particle size distribution of the dry bottom ash which is larger than that of the wet bottom ash. With the same amount of fly ash in the mix, the coarser the particle size, the higher is the workability of the fresh fly ash concrete.

Compressive Strength of Fractionated Fly Ash Concrete

The compressive strength of fractionated concrete are shown in Tables 4 and 6. The percentage variation of compressive strength as compared to the control mix are listed in Tables 5 and 7. The relationship between compressive strength of the dry and wet bottom ash concrete and its corresponding age are shown in Figs. 4 and 5., respectively.

The early strength of fractionated fly ash concrete is always lower than the control mix. With a part of cement replaced by the Class F fly ash, the mix generally produces lower strength because fly ash acts as a relatively inert component during the early period of hydration [26]. This result was also reported by Plowman [27], Langley, Carette, and Malhotra [28]. Experiment carried out under hot and humid climate also showed that the compressive strength of fly ash concrete at early ages were lower than those for the control concrete [29]. After 3 months of curing, the development of higher strength of fly ash concrete is commonly expected [30;31].

The compressive strength of original feed fly ash from wet bottom ash is higher than that from the dry bottom ash at the same age. This is primarily due to the finer particle size of the wet bottom ash than the dry bottom ash. The finer particles will react more faster than the coarser ones since they have more surface area. With the replacement of up to 35% by weight of cement by the dry bottom ash, the percentage of compressive strength gained of the fractionated fly ash at 1-day varies from 55.2% to 72.7% of the control strength, depending on the fineness of the fly ash. For the replacement of wet bottom ash, the percentage of compressive strength at 1-day varies from 67.5 to 76.0% of the control mix, from coarser to finer particle size of fly ash. For the very small particle sizes, 3F and 13F, the compressive strength of fractionated fly ash is equal to or higher than the control concrete prior to the age of 28 days. To achieve the same level of compressive strength as the control sample, it often takes more than 180 days for the concrete using the original feed fly ashes (dry or wet bottom ash).

It is interesting to note that the strength of the coarsest samples, i.e. 1CC35 and 18CC35, at the age of 180 days are only 83.2% and 85.5% of the control strength for both types of ash. Sample 18CC35 has residue retained on sieve No. 325 (45 um) 29% which is under the limit given by ASTM C-618 [16]. This result shows that the active particle of fly ash is lower than this size of sieve opening.

Table 4 Compressive Strength of the Dry Fractionated Fly Ash Concrete

Sample No.	Compressive Strength (MPa)							
	1-day	3-day	7-day	14-day	28-day	56-day	90-day	180-day
CHM	23.52	41.48	52.78	58.50	65.24	72.94	74.62	75.59
3FC35	17.10	35.98	46.82	54.88	66.76	78.05	81.55	83.44
5FC35	15.70	33.21	44.42	51.34	61.70	73.15	77.96	80.11
6FC35	15.65	32.50	43.86	50.53	59.64	70.54	75.37	79.41
10FC35	15.41	32.12	43.07	49.92	57.77	66.90	71.19	73.65
11FC35	13.26	29.30	39.66	45.24	53.79	62.33	64.81	67.97
1CC35	12.98	28.07	37.63	44.26	51.49	58.57	59.74	62.93
CHO35	14.36	29.48	40.67	46.97	55.61	65.63	69.21	72.97

Table 5 Percentage Compressive Strength of the Dry Fractionated Fly Ash Concrete

Sample No.	Percentage Compressive Strength (%)							
	1-day	3-day	7-day	14-day	28-day	56-day	90-day	180-day
CHM	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3FC35	72.7	86.7	88.7	93.8	102.3	107.0	109.3	110.4
5FC35	66.8	80.1	84.2	87.8	94.6	100.3	104.5	106.0
6FC35	66.5	78.4	83.1	86.4	91.4	96.7	101.0	105.0
10FC35	65.5	77.5	81.6	85.3	88.5	91.7	95.4	97.4
11FC35	56.3	70.7	75.1	77.3	82.5	85.5	86.9	89.9
1CC35	55.2	67.7	71.3	75.7	78.9	80.3	80.1	83.2
CHO35	61.0	71.1	77.1	80.3	85.2	90.0	92.8	96.5

Table 6 Compressive Strength of the Wet Fractionated Fly Ash Concrete

Sample No.	Compressive Strength (MPa)							
	1-day	3-day	7-day	14-day	28-day	56-day	90-day	180-day
CHM	23.52	41.48	52.78	58.50	65.24	72.94	74.62	75.59
13FC35	17.89	36.94	47.91	55.57	67.74	80.05	84.52	86.81
14FC35	17.52	34.32	46.17	53.18	64.66	77.12	81.26	84.20
15FC35	16.89	33.57	44.14	51.46	60.87	74.79	79.61	83.57
16FC35	16.14	32.99	43.21	49.66	59.27	70.39	75.59	81.05
18FC35	16.05	31.62	40.72	46.47	54.25	63.92	69.06	73.70
18CC35	15.87	31.02	39.72	45.10	51.39	59.52	61.59	64.61
CMO35	16.12	31.02	42.65	49.04	57.37	67.32	69.85	73.36

Table 7 Percentage Compressive Strength of the Wet Fractionated Fly Ash Concrete

Sample No.	Percentage Compressive Strength (%)							
	1-day	3-day	7-day	14-day	28-day	56-day	90-day	180-day
CHM	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
13FC35	76.0	89.1	90.8	95.0	103.8	109.7	113.3	114.8
14FC35	74.5	82.7	87.5	90.9	99.1	105.7	108.9	111.4
15FC35	71.8	80.9	83.6	88.0	93.3	102.5	106.7	110.5
16FC35	68.6	79.5	81.9	84.9	90.8	96.5	101.3	107.2
18FC35	68.2	76.2	77.2	79.4	83.2	87.6	92.6	97.5
18CC35	67.5	74.8	75.3	77.1	78.8	81.6	82.5	85.5
CMO35	68.5	74.8	80.8	83.8	87.9	92.3	93.6	97.0

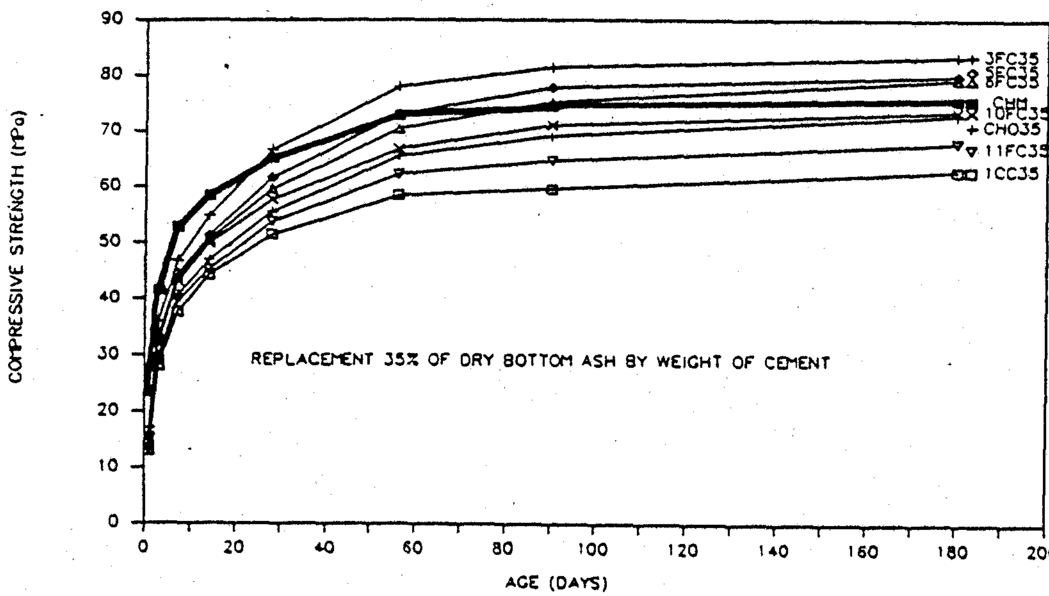

Fig. 4 Relationship between Compressive Strength of the Dry Fractionated Fly Ash and Age

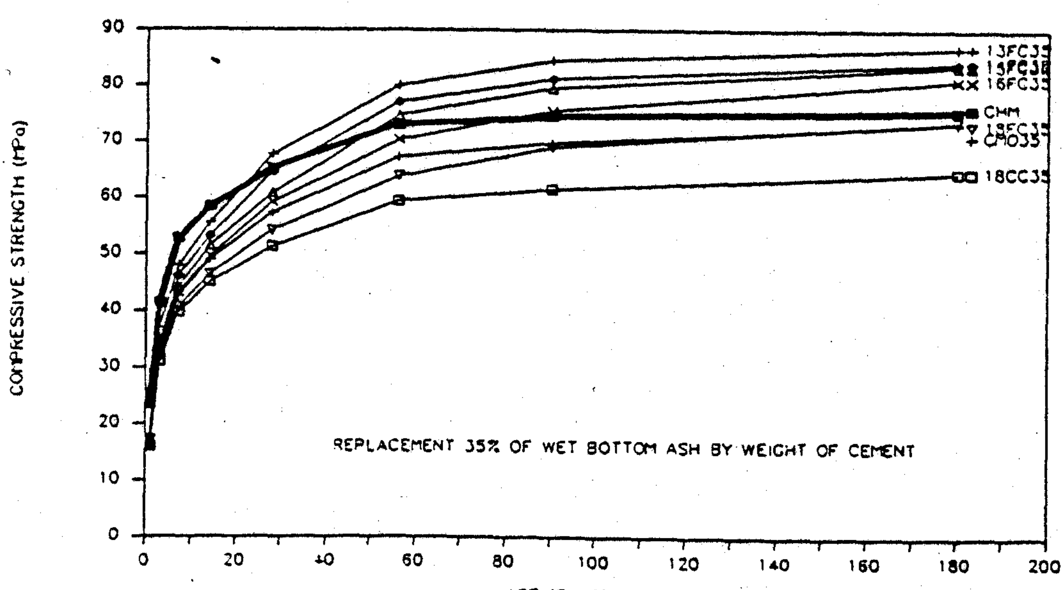

Fig. 5 Relationship between Compressive Strength of the Wet Fractionated Fly Ash and Age

CONCLUSIONS

From this investigation, the following conclusions can be drawn:

1. Chemical composition of fractionated fly ash varies slightly when fly ash is separated into different particle sizes.

2. The specific gravity of original feed of wet bottom ash is higher than that of the dry bottom ash. For the same type of fly ash, the finer the particle, the higher is the specific gravity of fly ash.

3. The workability of fresh fly ash concrete tends to reduce with the decrease of the particle size of fly ash.

4. Fineness of fly ash is a very important factor that affects the rate of pozzolanic activity. Finer particle of fly ash gives higher rate of pozzolanic reaction. The compressive strength of fractionated fly ash concrete is equal to or higher than the control strength before the age of 28 days with the finest particle of fly ash (3F35 and 13F35) when using as 35% replacement by weight of cement. For the large particle sizes, the compressive strength at the age of 180-day of samples 1CC35 and 18CC35 are only 83.2% and 85.5% of the control strength.

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