INVESTIGATION ON FLY ASH AS A PARTIAL CEMENT REPLACEMENT IN CONCRETE

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ABSTRACT

The use of high volume fly ash (HVFA) concrete fits in very well with sustainable development. High performance concrete is being widely used all over the world. High volume fly ash concrete mixtures contain lower quantities of cement and higher volume of fly ash (up to 60%). The use of fly ash in concrete at proportions ranging from 35 to 60% of total cementitious binder has been studied extensively over the last twenty years and the properties of blended concrete are well documented. The replacement of fly ash as a cementitious component in concrete depends upon the design strength, water demand and relative cost of ash compared to cement. This study investigated the strength properties of fly ash concrete. The specific gravity and chemical properties of fly ash, cement, coarse and fine aggregate were determined. The density of coarse aggregate was 2.8, fine aggregate was 2.6, water absorption of coarse aggregate 0.6%, water absorption of fine aggregate was 2%, fineness modulus of fine aggregate was 2.90 and fineness modulus of coarse aggregate was 6.90. Ordinary Portland cement was replaced with fly ash from 30 to 60% in steps of 30%, 40%, 50% and 60% by weight, mix proportioning was based on 1:2:4 mix ratio. Cubes (150 x 150 x150mm) were produced, cylinder (150 x 300mm) were used for determination of rapid chloride determination. All the cubes and the cylinder cubes were cured for 7 and 28 days respectively. The cubes and cylinder cubes were subjected to compressive strength tests after density determination at 7 and 28 days respectively. The specific gravity of fly ash was 2.20. The main constituents of fly ash as shown are silicon (as SiO_2), aluminium (as Al_2O_3) and iron oxide (as Fe_2O_3). The total amount of SiO_2, Al_2O_3, Fe_2O_3 was 80.38% for fly ash. These values are more than the minimum requirement (50% minimum) specified by ASTM C618 for type C ash. Calcium oxide (CaO) content was 3.50% fly ash. The chemical properties of fly ash are in compliance with the standard and due to high overall content, it was used as cement replacement. This study has shown that increase in the level of fly ash from 15% to 60% lead to an increase in the compressive strength of hardened concrete, while intake of fly ash up to 75% lead to reduction in the compressive strength of hardened concrete and it was observed that 75% replacement of fly ash did not meet up with the require compressive strength at 28 days. This study also shown that the ion chloride penetration satisfied the required standard of ASTM C1202 - 97.

Key Words: Concrete, Fly Ash, specific Gravity, Compressive Strength, Density and RCPT.

1.0 INTRODUCTION

The cost of materials is currently so high that only governments, corporate organizations and wealthy individuals can afford to do meaningful construction. The use of high volume fly ash concrete fits in very well with sustainable development. High volume fly ash concrete mixtures contain lower quantities of cement and higher volume of fly ash (up to 60%). The use of fly ash in concrete at proportions ranging from 35 to 60% of total cementitious binder has been studied extensively over the last twenty years and the properties of blender concrete are well documented. The replacement of fly ash as a cementitious component in concrete depends upon several factors. The design strength and workability of the concrete, water demand and relative cost of fly ash compared to cement. From the literature it is generally found that fly ash content in the cementitious material varies from 30 to 80% for low strength (20mpa) to high strength (100mpa).

Ramme et al (1989), presented two case histories wherein 70% cement was replaced by class C fly ash to pave a 254 mm thick road way. To obtain high workability and durability a high range water reducing agent and an air entraining agent was added to the concrete mix the other case reported by the same author's involved placing of the same high performance concrete in the construction of 138KV transformer foundations. No problems were reported during or after construction in both projects and the use of high report during or after construction in both projects and the use of high volume fly ash concrete, resulted in considerable economy and technical benefits.

Langley et al (1990) reported two case histories where high volume fly ash concretes were used with class fly ash constituting 55% of cementitious material along with a super plasticizer. In one case, where columns, beams and floor slab in a building complex require 50mpa concrete at 120 days, the high performance concrete yielded concrete with 74mpa compressive strength at 120 days, thus exceeding the strength requirement. No unexpected problems were reported and the high volume of fly ash proved to be an economical solution for the particular project.

In India, fly ash mission has initiated projects on use of higher volume fly ash concrete in construction. Gujrat Ambuja cements had laid down a high volume fly ash (50%) concrete road at their ropar plant, Punjab. The grade of the concrete was M-40.

Malhotra et al (1990), studied in detail the properties of concrete with a wide range of Canadian fly ashes at 58% of the total cementitious materials. These concretes were tested for compressive strength, creep strain and resistance to chloride ion penetration at various ages up to one year. The results of study by Joshi et al (1994), indicated that with fly ash replacement level up to 50% by cement weight, concrete with 28 days strength ranging from 40 to 60 mpa and with adequate durability can be produced with cost saving of 16% by 50% replacement level.

Bouzouboa et al (2004) at Canmet Canada have done studies on the mechanical properties of concrete made with blended high volume fly ash cements. Physical properties of high volume fly ash cements and mortars had also been studied. The use of the high volume fly ash cements improves the resistance of the concrete to the chloride ion penetration. The present study investigates the potential of fly ash as cement replacement in concrete. The objectives are to reduce the amount of ordinary Portland cement needed in building construction so as to achieve economic construction and sustainable development through the preservation of the environment.

Ordinary Portland cement (OPC) is acknowledged as the major construction material throughout the world. The production rate is approximately 2.1 billion tons/year and is expected to grow to about 3.5 billion tons/year by 2015 (Coutinho, 2003).

2.0 METHODOLOGY

The methodology adopted comprised of both preliminary and experimental investigations carried out using the study material and these are presented as follows:

2.1 Preliminary Investigations

For the preliminary investigations, fly ash was subjected to physical and chemical analyses to determine whether they are in compliance with the standard used

Plate 2.0: Fly Ash

The experimental program was designed to investigate fly ash as partial cement replacement in concrete. The replacement level of the cement by fly ash are selected as 15%, 30%, 45%, 60% and 75% for standard size of cubes for the C30 grade of concrete. The specimens of standard cubes (150 x 150 x 150mm), was casted with fly ash. Compressive machine was used to test the specimen. The specimens were casted with C35 grade of concrete with different replacement levels of cement from 0 to 75% of fly ash. Seventy two samples was casted and the cubes were put in curing tank for 7, 14, 21 and 28 days and density of the cube and compressive strength were determined and recorded down accordingly.
The other materials used are listed as follow:

1) **Cement**
   Ordinary Portland cement produced by QNCC and sourced from the open market was used in this study. The cement conformed to the requirements of BS 12 (1996)
2) **Aggregates**
   They are the inert filler in the mixture which constitute between 70 – 75% by volume of the whole mixture. The sand used was collected from Qatar washing sand plant, it was clean and free from organic material retained on a 4.7mm BS 410 test sieve and contained only so much fine materials as was permitted for various sizes in the specification.
3) **Water**
   The water used for the study was free of acids, organic matter, suspended solids, alkalis and impurities which when present may have adverse effect on the strength of concrete.

Preparation of Specimens

In this study, a total number of 12 cubes for the control and cement replacement levels of 15%, 30%, 45%, 60% and 75% were produced respectively. For the compressive strength, 150mm x 150mm x 150mm cubes mould were used to cast the cubes and 3 specimens were tested for each age in a particular mix (i.e the cubes were crushed at 7, 14, 21 and 28 days respectively). All freshly cast specimens were left in the moulds for 24 hours before being de-moulded and then submerged in water for curing until the time of testing. Table 2.0 shows the number of specimens cast and the testing arrangement.

Table 2.0: Shows Number of Cubes and Ages for each Test.

SPECIMENS	TESTING AGE (DAYS)			
	7	**14**	**21**	**28**
FA (0%)	3	3	3	3
FA (15%)	3	3	3	3
FA (30%)	3	3	3	3
FA (45%)	3	3	3	3
FA (60%)	3	3	3	3
FA (75%)	3	3	3	3

Table 2.1: Shows Number of Cubes and ages (RCPT).

SPECIMENS	TESTING AGE (DAYS)
	28
FA (0%)	3
FA (15%)	3
FA (30%)	3
FA (45%)	3
FA (60%)	3
FA (75%)	3

Mix Proportioning

Mix proportioning by weight was used and the cement/dried total aggregates ratio was 1:2:4. Fly ash was used to replace OPC at dosage level of 15%, 30%, 45%, 60% and 75% by weight of the binder. The mix proportions were calculated and are presented in table 2.2

Table 2.2: Mix Proportion for 35 Mpa Concrete.

Materials	Mix Proportion (Kg)					
	Control	**FA (15%)**	**FA (30%)**	**FA (45%)**	**FA (60%)**	**FA (75%)**
Cement (Kg)	380	323	266	209	152	95
FA (Kg)	0	57	114	171	228	285
Water (Kg)	152	152	152	152	152	152

Fine Aggregate (Kg)	760	760	760	760	760	760
Coarse Aggregate (Kg)	1170	1170	1170	1170	1170	1170
Water/Binder Ratio	0.40	0.40	0.40	0.40	0.40	0.40

Testing of Specimens.

Compressive strength test were carried out at specified ages on the cubes. This consisted of the application of uniaxial compressive load on the cube until failure at which, the required failure of each cube was noted (fig 1). Prior to testing, the density of each cube was determined using standard procedures for density determination.

Plate 2.1: Cube inside Compressive Strength Machine

RESULTS AND DISCUSSION

3.1 Chemical Analysis

The results of the chemical analysis of cement and fly ash are shown in table 3.0. The main constituents of fly ash as shown are silicon (as SiO_2), aluminium (as Al_2O_3) and iron oxide (as

Fe_2O_3). The total amount of SiO_2, Al_2O_3 and Fe_2O_3 was 80.38% for fly ash. These values are more than the minimum requirement (50% minimum) specified by ASTM C618 for type C fly ash. Calcium oxide (CaO) content was 3.50% for fly ash. The chemical properties of fly ash are in compliance with the standard and due to high overall content, it was used as cement replacement.

3.2 Specific Gravity

Specific gravity was the physical property determined and this was carried out on the fly ash. The specific gravity obtained for fly ash was 2.20 and the specific gravity of cement was 3.10. This property is essential if high strength concrete is to be designed through volume displacement methods.

3.3 Results for RCPT

The ASTM C 1202- 94 describe the method to determine the rapid chloride permeability and this was developed as a quick test to measure the rate of transport of chloride ions in concrete. Concrete disc size 100mm diameter and 150mm thickness with and control samples were subjected to RCPT by impressing 60V. Two halves of the specimens were sealed with PVC container of diameter 90mm. One side of the container was filled with 3% sodium chloride solution (side of the cell will be connected to the cathode terminal of the power supply) and other side of the cell were connected to the cathode terminal of the power supply and on other side, sodium hydroxide solution was poured and connected to anode terminal (fig 2). After six hours the results was printed out from the system.

Figure 2.0: Experimental Set up of RCPT.

Table 3.0: Physical and Chemical Analysis of Portland and Fly Ash.

Property	BS Standard	Portland Cement (%)	Fly Ash (%)
Silicon dioxide (SiO_2)	_	21.27	58.65
Aluminium Oxide (Al_2O_3)	_	3.62	15.65
Ferric Oxide (Fe_2O_3)	_	4.40	6.08
Calcium Oxide (CaO)	_	64.71	3.50
Magnesium Oxide (MgO)	5.0 Max	2.92	0.28
Sulphur trioxide (SO_3)	2.5 Max	1.65	0.16
Alkalies ($Na_2O + 0.658K_2O$)	_	0.33	2.31
Loss of Ignition (LOI)	3.0 Max	0.45	1.12
Insoluble Residue (IR)	1.5 Max	0.58	_
Tricalcium Silicate (C_3S)	66.7 Min	74.18	_
Dicalcium Silicate (C_2S)	66.7 Min	74.18	_
Tricalcium Aluminate (C_3A)	3.5 Max	2.17	_
Tetracalcium Aluminoferrite (C_4AF)	_	13.38	_
CaO/SiO_2	2.0 Max	3.04	_
Chloride (Cl)	0.10 Max	0.014	_
Specific gravity	_	3.10	2.20
Specific Surface/Fineness Blaine Air Permeability test (cm^2/g)	_	3300	3970

Soundness (Le Chatelia Expansion)	10.0 Max	5	_
Compressive Strength 2 days	20.0 Min	20.28N/mm^2	_
Compressive Strength 28 days	42.5 Min	45.78N/mm^2	_
Initial Setting Time (Vicat Test)	60 Minutes	150 Minutes	_

Table 3.1: Sieve Analysis of Coarse Aggregate.

Sieve Size (mm)	20mm	10mm	Mixed	BS 812
20	100	100	100	95-100
10	5	100	52.5	25-55
5	0	5	1.8	0-10

Table 3.2: Sieve Analysis of Fine Aggregate.

Sieve Size (mm)	% Passing	Specification Limit
10	100	100
5	96.3	90-100
2.36	86.0	85-100
0.60	60.4	60-79
0.300	19.8	12-40
0.150	6.5	0-10
0.750	2.0	0-5

Physical Properties of Aggregates

Density of coarse aggregate is 2.8

Density of fine aggregate is 2.6

Water absorption of coarse aggregate is 0.6%

Water absorption of fine aggregate is 2.0%

Fineness modulus of fine aggregate is 2.90

Fineness modulus of coarse aggregate is 6.90

Density of Cubes

Table 3.3 shows the average density of cured cubes before they were subjected to compressive strength test.

Table 3.3: Density of Cubes at Testing Ages

% Fly Ash Rep. **Density (g/cm^3)**

	0 days	**7 days**	**14 days**	**21 days**	**28 days**
0	2.56	2.57	2.59	2.61	2.67
15	2.49	2.50	2.52	2.55	2.56
30	2.44	2.46	2.49	2.53	2.54
45	2.40	2.42	2.44	2.47	2.50
60	2.39	2.40	2.42	2.46	2.49
75	2.38	2.39	2.40	2.44	2.46

Table 3.3 show that the density of the concrete decreased with increased in percentage of fly ash.

3.4 Compressive Strength Result

The results of the compressive strength test are presented in table 3.4 and fig 3 below.

Table 3.4: Compressive Strength Test Results for Fly Ash Concrete

% Fly Ash Rep **Concrete Strength (mpa)**

	7 days	**14 days**	**21 days**	**28 days**
0	37.5	38.9	41.8	46.5
15	35.8	37.0	40.5	45.5
30	35.9	37.5	40.8	47.6
45	36.5	38.0	41.3	50.5
60	40.5	42.3	45.0	52.5
75	24.3	29.5	31.5	34.0

GRAPH

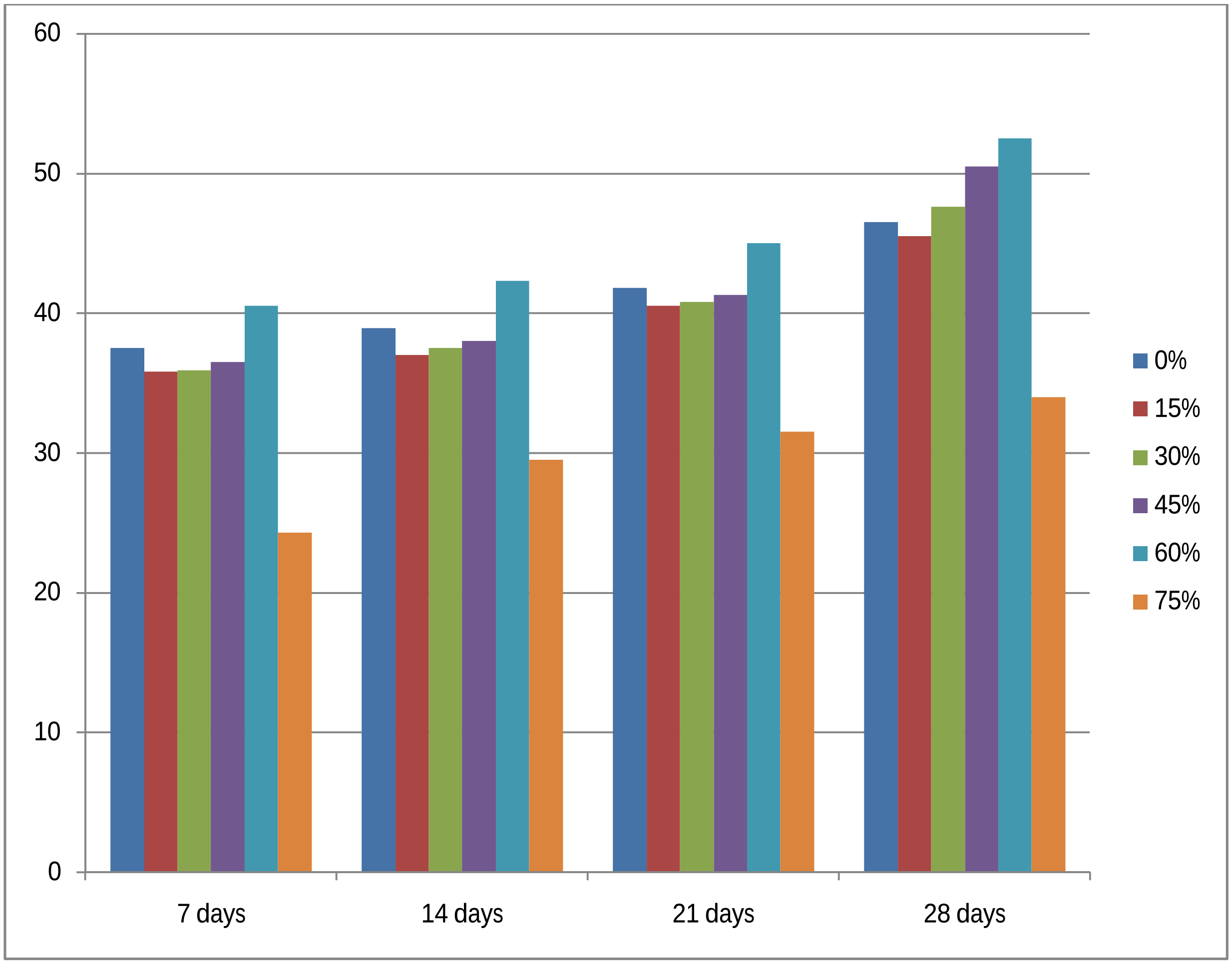

Fig 3.0: Showing the Curing days against Compressive Strength.

Table 3.5: showing results of RCPT of 35mpa grade of concrete

% Fly Ash	Rapid Chloride Permeability Test Results					
	28 days Comp Strength			Max Current reached during Test		
	i	ii	iii	i	ii	iii
0	47.0	46.5	48.5	0.0250	0.0267	0.0269
15	45.5	44.6	47.5	0.0585	0.0575	0.0594
30	48.5	49.5	50.5	0.0745	0.0755	0.0763
45	55.8	60.5	62.5	0.1000	0.1100	0.1201
60	55.0	64.0	66.5	0.1250	0.1430	0.1560
75	34.0	35.0	34.4	0.0500	0.0543	0.0567

Chloride Permeability Based on Charge Pass			Acceptable Limit as per ASTM	
i	ii	iii	Charge Passed	Chloride ion Penetration
2400	2247	2230	Greater than 4000	High
1026	1044	1010	Greater than 4000	High
805	795	786	2000 - 4000	Moderate
600	545	500	1000 - 2000	Low
480	420	385	100 - 1000	Very Low
1200	1105	1058	Less than 100	Negligible

Results		
i	ii	iii
m	m	m
m	m	m
L	L	L
V.L	V.L	V.L
V.L	V.L	V.L
L	L	L

3.0 CONCLUSIONS AND RECOMMENDATIONS

From the results of the study carried out, the following conclusions can be made:

1) Cement replacement up to 60% with fly ash leads to increase in compressive strength, for C35 grade of concrete. From 75% there was a decrease in compressive strength for 7, 14, 21 and 28 days curing period was not up to targeted strength at 28 days (Table 3.4).
2) The maximum replacement level of fly ash was 60% for C35 grade of concrete.
3) The use of fly ash in concrete will possibly reduce cost of concrete.
4) Fly ash concrete of C35 grade in table 3.5 has shown improved resistance to chloride ion penetration and reduced water permeability. The use of fly ash influences the physiochemical effects associated with pozzolanic and cementitious reactions that result in pore size reduction and grain size reduction phenomena.

Based on the conclusion arrived at, the following recommendations are made for future work:

1) It is recommended that testing of concrete produced with 75% fly ash be extended to 56 or possibly 90 days to further determine the pozzolanic ability of the concrete.
2) Detailed cost analysis should be carried out to determine the level of savings possible from the use of fly ash in concrete.

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