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Performance Evaluation of High-Strength High-Volume Fly Ash Concrete

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Abstract- In the present study, high strength high volume fly ash concrete of M70 grade is developed and its durability properties such as water absorption capacity, porosity, and sorptivityare ascertained. It was found that high volume fly ash does not yield high strength so silica fume is added for early strength gain and for later strength gain lime required for complete pozzolonic action is added to achieve high performance concrete. In this study after testing for various combinations of quaternary blended concrete it was reported that 30% cement +70% fly ash as total powder achieves high strength of nearly 70 MPa, when silica fume of 10% by weight of powder and 30% of lime by weight of powder are added to the total powder content. The high strength high volume concrete developed with this optimum quantities of quaternary blends will be evaluated for the performance.It was found that water absorbtion in high strength high volume fly ash concrete reduced by nearly 85% and porosity is reduced by 34%.

Index Terms – high strength concrete, high performance concrete, high volume fly ash concrete, quaternary blended concrete, lime added concrete.

I. INTRODUCTION

Fly ash is abundantly available industrial by-product which had serious disposal problem. So researchers addressed this environmental concerned fly ash production and disposal problem by recommending to use in construction industry as a concrete ingredient. The use of fly ash in concrete has gained importance due to its high silica content which reacts with calcium hydroxide produced during hydration resulting in pozzolonic action which imparts later strength to the concrete. Fly ash usage in high quantities may affect the early strength gain in concrete but will achieve similar strength at later age. Especially in high volume fly ash concrete, due to presence of high percentage of fly ash and less cement quantity, the strength gain in early stages is very less and also due to less quantity of cement used in concrete the production of hydration product calcium hydroxide is also very less.

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So to take maximum advantage of pozzolanic action due to presence of high silica content, equal amount lime is required for optimum pozzolanic action. So due to less availability of lime produced during hydration, hydraulic lime is added to the powder content to promotepozzolanic action.

II. OBJECTIVES

1. To develop high strength high volume fly ash concrete of 70 MPa compressive strength.
2. To optimize cement, fly ash, silica fume and lime quantities in high strength high volume fly ash concrete.
3. To determine the split-tensile and flexural strength of high strength high volume fly ash concrete.
4. To evaluate the water absorption ability and porosity of high strength high volume fly ash concrete.

III. EXPERIMENTAL INVESTIGATIONS

A) Mix Design Using Entroy And Shacklock Method

Entroy and Shacklock method is used to arrive at the quantities of M70 grade concrete and after several mix trials the following quantities are arrived at. Water/cement ratio is assumed as 0.3 and cement content is limited to 450 kg/m^3.

B) Materials

Fly ash – F class fly ash is used in the present study. Various fly ashes from different sources are obtained and checked for pozzolonic reactivity and Strength activity Indices. The one with maximum reactivity and very fine is chosen for study.

C) Mix Quantities After Various Trials

Table 2 presents the mix quantities for OPC and high volume fly ash concrete mixes and table 3 presents the compressive strengths of OPC and high volume fly ash concrete mixes.

To improve the early strength in high volume fly ash concrete, Silica fume of 10% by weight of powder (cement+ fly ash) is used. Table 4 gives improved mix quantities of high volume fly ash concrete with silica fume as additive.

Table 1: Quantities for high strength concrete (M70)made with W/C =0.30

Mix	Cement (kg/m³)	Water (Litres) (w/c=0.30)	Aggregate		SP (litre/m³)
			Fine (kg/m³)	Coarse (kg/m³)	
Reference	450	132	940	996	14

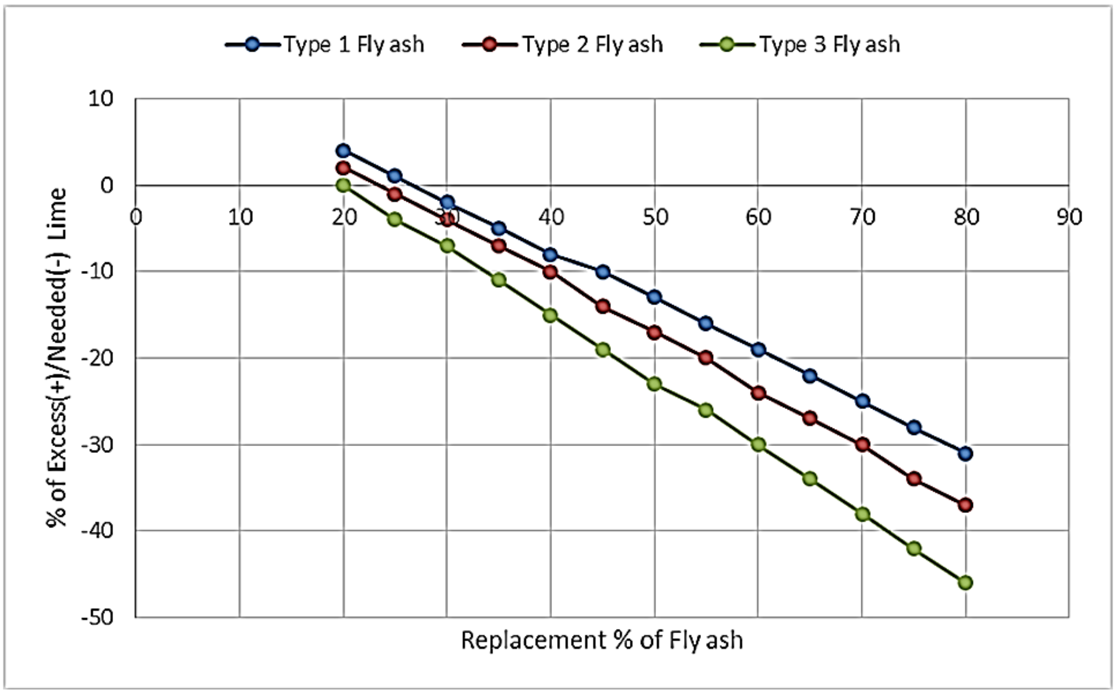

Fig 1 –Excess Lime or Lime needed for various fly ashes

Table 2 - Mix quantities of high volume fly ash concrete

Mix	Cement %	Fly ash %	Cement (kg/m³)	Flyash (kg/m³)	Water (kg/m³)	Aggregate		SP (litre/m³)
						Fine (kg/m³)	Coarse (kg/m³)	
Mix1(FAC0)	100	0	450	0.00	132	940	996	14
Mix2(FAC70)	30	70	135	315	132	940	996	14

Table 3 - Compressive strengths of OPC and high volume fly ash concrete mixes

Type	Cement %	Fly ash %	Compressive Strength (MPa)		
			7 days	28 days	60days
Mix1(FAC0)	100	0	35.9	55.3	60.7
Mix2(FAC70)	30	70	10.7	22.1	32.9

Table 4- Mix quantities of high volume fly ash concrete with 10% silica fume as additive

Mix	Powder		SF %bwp (Additive)	Cement (kg/m³)	Flyash (kg/m³)	Silica Fume (kg/m³)	Water (kg/m³)	Aggregate		SP (litre/m³)
	Cement % bwp	Fly ash %bwp						Fine (kg/m³)	Coarse (kg/m³)	
Mix11(FAC0+SF5)	100	0	5	450	0	22.5	132	940	996	14
Mix21(FAC70+SF10)	30	70	10	135	315	45	132	940	996	14

D) STRENGTH STUDIES

Table 5 presents compressive strengths of high volume fly ash concrete with silica fume as additive.

Table 5- Compressive strengths of high volume fly ash concrete with silica fume as additive

Type	Cement % bwp	Fly ash %bwp	SF %bwp	Compressive Strength (MPa)		
				7 days	28 days	60days
Mix11(FAC0+SF5)	100	0	5	43.08	66.36	72.84
Mix21(FAC70+SF10)	30	70	10	15.41	31.82	47.38

*%bwp-by weight of powder(Cement + fly ash)

Addition of mere 10% silica fume is not enough to achieve desired compressive strength of 70 MPa. Since fly ash content available is more so is reactive silica which is main component of fly ash. For maximum usage of reactive silica in fly ash for pozzolonic reaction, equal amount of calcium hydroxide should be available. Since the calcium hydroxide available through hydration is not enough for optimal pozzolonic reaction, excess lime is required in the form of additive to cement +fly ash + silica fume mixture. From the studies conducted it was found that 30% lime is required for maximum compressive strength.Table 6 presents compressive strengths of high volume fly ash concrete with silica fume as additive. Table 7 and 8 presents corresponding spit-tensile and flexural strengths of high strength OPC and high strength high volume fly ash concretes.

Table 6- Compressive strengths of high strength OPC and high strength high volume fly ash concrete mixes

Mix Type	Powder		SF %bwp	Hydraulic Lime %bwp	Compressive Strength (MPa)		
	Cement % bwp	Fly ash %bwp			7 Days	28 Days	60 Days
Mix12(FAC0+SF10)	100	0	10	-	41.70	**69.63**	**77.41**
Mix22(FAC70+SF10)	30	70	10	30	40.51	**82.35**	**83.06**

Table 7- Split tensile strengths of high strength high volume fly ash concrete mixes

Mix Type	Powder		SF %bwp	Hydraulic Lime %bwp	Compressive Strength (MPa)	
	Cement % bwp	Fly ash %bwp			28 Days	60 Days
Mix12(FAC0+SF10)	100	0	10	-	4.46	4.51
Mix22(FAC70+SF10)	30	70	10	30	4.54	4.56

Table 8- Flexural strengths of high strength high volume fly ash concrete mixes

Mix Type	Powder		SF %bwp	Hydraulic Lime %bwp	Compressive Strength (MPa)	
	Cement % bwp	Fly ash %bwp			28 Days	60 Days
Mix12(FAC0+SF10)	100	0	10	-	5.01	5.28
Mix22(FAC70+SF10)	30	70	10	30	5.44	5.47

E) EVALUATION OF WATER ABSORPTION ABILITY AND POROSITY

In this test, water absorption and porosity of high strength high volume fly ash concrete as per ASTM C642-13.This test gives an indication of presence of voids and their distribution. 100mm cubes are casted and tested for permeation properties.At specific interval, the amount of water absorbed with respect to that of dry sample is expressed as:

$$WA_i\% = 100 \times (W_i - W_o)/W_o$$

Where W_i= mass (kg) of the wet specimen at any instant time T; W_o = mass (kg) of the dry specimen. Total duration of test is 24 hrs.and readings are taken at intervals (15 min, 30 min, 1 hour, etc.) for the first 3 hours and then be weighed after 8 hours and again after 24- hours until no more absorption is observed.

Water Absorption (WA) = [(B-A)/ A] x 100

Bulk density = G_1 = [(A)/ C- D]x ρ

Apparant density =G_2 =[(A)/ A-D]xρ

Permeable Voids (PV) = [(G_2 - G_1)/ G_2] x 100

where: A= mass of oven-dried sample in air, kg; B= mass of surface-dry sample in air after immersion, kg ; C= mass of surface-dry sample in air after immersion and boiling, kg and D= apparent mass of sample suspended in water, kg.

G_1= dry bulk density (kg/m^3) and G_2= apparent density (kg/m^3), ρ= density of water (1000 kg/m^3)

Porosity 'P' or interconnected pore space is given as-

Porosity (%) = (V_v/V) = (Weight of Saturated Specimen- Weight of Dry Specimen) / ρV

Where, V_v = Volume of voids in cc= Weight of Saturated Specimen- Weight of Dry Specimen in grams;

V = Volume of specimen in cc = 100 x 100 x100 mm^3;

ρthe unit mass of water (1 g/cc); Eand Fdenote the weight of the dried and fully saturated samples, respectively.

The equation to find the apparent porosity is-

Apparent porosity (%) = [(X-Y)/ (X-Z)] x100

Where X= mass of saturated specimen (immersed in water for 48 hours and weighed dried), Y= Mass of dried specimen and Z= mass of specimen under water suspension.

Porosity of concrete is the ratio of the volume of voids of the specimen to its bulk volume. Porosity contemplates both permeable and impermeable voids whereas apparent porosity deliberates only impermeable voids. The table and fig. shows the amount of water absorption with time. Table 9to 11 and fig 2give the water absorption (WA), Permeable voids and Apparent porosity of high strength concrete made with OPC and high strength concrete made with high volume fly ash.

Table 9 - Water Absorption at different time intervals of high strength concrete made with OPC and high strength concrete made with high volume fly ash

Measuring Intervals t_i (min)	Water Absorption			
	High strength concrete made with OPC		High strength concrete made with high volume fly ash	
	W_o= 2.63 kg		W_o= 2.64 kg	
	W_i(kg)	WA_i(%)	W_i(kg)	WA_i(%)
0	2.651	0.798	2.642	0.076
15	2.662	1.217	2.653	0.492
30	2.671	1.559	2.654	0.530
60	2.672	1.597	2.655	0.568
90	2.673	1.635	2.655	0.568
180	2.674	1.673	2.655	0.568
480	2.674	1.673	2.655	0.568
1440	2.674	1.673	2.655	0.568

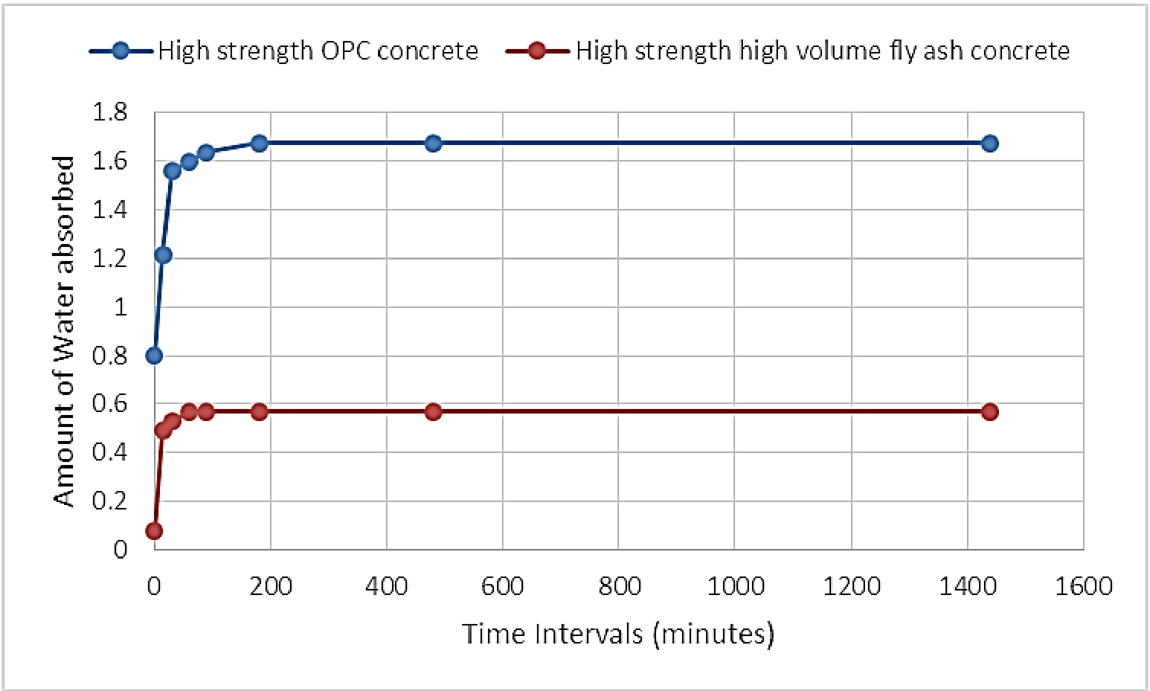

Fig 2- Plot showing amount of water absorption with time

Table 10 - Water Absorption Capacity (WAC), Volume of Permeable Voids and Apparent porosity of high strength concrete made with OPC and high strength concrete made with high volume fly ash

	High strength concrete made with OPC	High strength concrete made with high volume fly ash
A	2.632	2.643
B	2.671	2.652
C	2.692	2.671
D	1.512	1.510
Bulk density (G_1) (kg/m^3)	2230.508	2276.486
apparent density (G_2)(kg/m^3)	2350	2332.745
Water Absorption (WA) (%)	1.482	0.341
Permeable voids (PV) (%)	5	2.4
Apparent porosity (%)	3.365	0.778

Table 11- Porosity of high strength concrete made with OPC and high strength concrete made with high volume fly ash

	High strength concrete made with OPC	High strength concrete made with high volume fly ash
Weight of Saturated Specimen (kg)	2.662	2.661
Weight of Dry Specimen (kg)	2.632	2.651
Porosity, P at 28 days	0.030	0.020
Decrease in Porosity	-	34%

IV. CONCLUSIONS

Based on the experimental studies to evaluate the performance of high strength high volume fly ash concrete, the following conclusions are outlined-

1. High volume fly ash concrete is developed with 70% fly ash as cement replacement. This concrete cannot achieve high strength due to presence of high amount of fly ash presence. Fly ash has high amount of reactive silica which remains unreacted due to unavailability of $CaOH_2$ in the concrete due to which strengths are very less in high volume fly ash concrete.
2. To attain high strength with high volume fly ash, concrete is added with 10% silica fume. Silica fume will enhance the microstructure of the structure significantly but to attain compressive strength of 70 MPa is not possible unless the reactive silica in the fly ash is completely utilized in forming CSH gel as a product of pozzolonic action.
3. To utilize the silica present in fly ash for pozzolonic reaction, lime reactivity of fly ash is evaluated in terms of pozzolonic index and strength activity index.
4. Excess lime required to react with fly ash will be evaluated and is provided in the form of lime as additive. In the present study, 30% lime has yielded better results in terms of high strength gain.
5. Final high strength quaternary blended mix is made up of 30% cement, 70% fly ash, 10% silica fume and 30% lime with water cement ratio of 0.3.
6. Water absorption studies revealed that in high strength high volume fly ash concrete, water absorption ability has reduced by 75%.Permeable voids in high strength high volume fly ash concrete are reduced by 50%.
7. Total porosity of high strength high volume fly ash concrete is reduced by 34% but apparent porosity is reduced by 75%. This indicates that high strength high volume fly ash concrete is a high performance concrete.
8. 8.High strength high volume fly ash concrete has less water absorbtion ability due to its dense microstructure and reduced pore interconnectivity. Pozzolonic products reduce both permeable and impermeable pores thereby enhancing the performance of the high volume fly ash concrete.

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