OPEN ACCESS
International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Optimization and Development of High-Strength High-Volume Fly Ash Concrete Mixes

Ch Mounika, V Srinivasa Reddy, M V Seshagiri Rao, S Shrihari

Abstract-Cement is the most abundantly used ingredient in the production of concrete due to which its production and use has increased manifold. To reduce the carbon footprint left by the cement production, fly ash is used as cement replacement in concrete. Past research studies suggest that the fly ash replacement can be upto 40% beyond which there will be drastic reduction of strength. In the present study, high strength concrete mix of 70 grade is developed with high volume fly ash of 70% as cement replacement. Silica fume of 10% and hydraulic lime of 30% are used as additives in the development of M70 grade high-strength high-volume fly ash concrete. In the present paper, three types of fly ashes are considered for the study of which one which is ultrafine is chosen based on the pozzolanic index and strength activity index. Excess lime needed for various percentage of fly ashes is evaluated based on the empirical equationsgiven by the Dunstan Jr andZayed.

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

I. INTRODUCTION

Usage of concrete has increased as construction activities all over the world has increased considerably due to which production and cement has increased extensively leading to emission of high amount of carbon dioxide which is a cause of concern. So in order to reduce the carbon footprint, cement production and use are to be controlled in such a way that cement should be replaced by alternative cementitious materials. Pozzolans can be used as cement replacement to some extent deriving the advantages of both hydration and pozzolonic reactions during hardening stage of concrete. Studies reveal that pozzolan such as fly ash can replace cement upto 40% but the rate of strength gain is slow during initial age but gains strength during later age with superior durability properties. Some studies show that addition of silica fume can enhance the mechanical properties of the concrete especially at the initial age. Due to presence of high amount of pozzolan which has reactive silica as major component, the requirement of calcium hydroxide is more to reactive silica available from fly ash.

Manuscript published on 30 September 2019
* Correspondence Author
Ch Mounika*, Student, M.Tech. (Structural Engineering), Department of Civil Engineering, Hyderabad, India.
V Srinivasa Reddy, Professor of Civil Engineering, GRIETHyderabad, India. Email- vempada@gmail.com
M V Seshagiri Rao, Professor of Civil Engineering, CVR College of Engineering Hyderabad, India.
S Shrihari, Professor of Civil Engineering, VJIT Hyderabad, India

Since the cement content available is less so the production of calcium hydroxide is also very less,demanding for more calcium hydroxide for CSH gel. So appropriate amount of lime can be supplied as additive to cater to the need of calcium hydroxide required to reactive with reactive silica in fly ash..

II. OBJECTIVES

1) Mix quantities for the high strength concrete (M70) are obtained using Entroy Shacklock Method
2) Choice of type of fly ash based on pozzolanic index and strength activity index
3) Determination of optimum percentage of fly ash for high volume fly ash concrete
4) Determination of optimum percentage of silica fume
5) Determination of optimum amount of lime to be used for high strength high volume concrete

III. EXPERIMENTAL INVESTIGATIONS AND THEIR TEST RESULTS

A) MIX DESIGN

Mix design procedure for high strength concrete (M70) is based on Entroy Shacklock empirical method. Quantities arrived at are presented in the table 1 below for which the achieved compressive strength at 28 days is 52.6 MPa.
Assuming W/C =0.30 and cement= 450 kg/m^3 to develop high strength concrete, several trails are conducted on the calculated quantities and new quantities are arrived at. Fine and Coarse aggregates are adjusted in such a way that the maximum compressive strength that can be obtained is 55.3 MPa and quantities are tabulated in table 2as follows.

B) LIME REQUIREMENT FOR HIGH VOLUME FLY ASH CONCRETE

For the present study, three types of fly ashes from various sources are procured and tested for their reactivity for pozzolonic action. The one having more pozzolonic index will be chosen to develop high strength high volume concrete.The lime required at 28 days can be calculated from table3. Full hydration is assumed at 28 days and the lime produced by hydration is assumed to be 25%. Calculations for lime needed for 100% pozzolanic reaction as per Dunstan Jr&Zayed 2006 are given in table 3.
Table 4 presents the cement mortar mix quantities for calculating pozzolanic index (PI). According to ASTM C 618, fly ash to be used in concrete has to satisfy the “SAI-StrengthActivity Index”, which is used to measure the reactivity of the fly ash. Strength Activity Index is the measure of percentage of strength of mortar made with 20% mass replacement of cement with pozzolana to that of a strength of cement mortar designed at the age of 7 or 28 days for water/powder ratio of
0.484.

To evaluate the reactivity of fly ash, Pozzolonic Index is estimated from the equations mentioned in table 5and its corresponding values are tabulated in table 6. Table 7 presentsthe pozzolonic indices and strength activity indices of various fly ashes used for the study.

Table 1: Quantities for high strength concrete (M70)

Concrete Mix	Cement (kg/m^3)	Water (Litres)	Aggregate		SP (litre/m^3)
			Fine (kg/m^3)	Coarse (kg/m^3)	
M70 grade	501.4	115.8	832.2	1008	11

Table 2: Quantities for concrete made with W/C =0.30

Mix	Cement (kg/m^3)	Water (Litres) (w/c=0.30)	Aggregate		SP (litre/m^3)
			Fine (kg/m^3)	Coarse (kg/m^3)	
Reference	450	132	940	996	14

Table 3-Calculations for lime required for 100% pozzolanic reaction

Powder content	Q
Weight of Fly ash	Pp
Weight of Cement	Pc
Pozzolanic Index (reactivity of pozzolana with $Ca(OH)_2$)	PI
Free Lime available during hydration	0.25 *Pc*Hx
Reactive pozzolan	PI*Pp
Lime required for 100% pozzolana action	1.85*PI*Pp
Excess lime/ Lime needed= Free Lime available during hydration - Lime required to react with pozzolana	0.25*Pc*Hx - 1.85*PI*Pp

Table 4- Mix quantities and compressive strength of cement mortar specimens

Mix	Cement (%)	Fly ash (%)	Powder Content		Sand gm	w/p ratio	W Water ml	Compressive Strength 28 days (MPa)
			Cement gm	Fly Ash gm				
OPC	100	0	200 (C)	0	600	0.484	96.8	53.1(F_c)
FA Type 1	80	20	160(C_1)	40	600	0.484	96.8	46.8 (F_{cp1})
FA Type 2	80	20	160 (C_2)	40	600	0.484	96.8	49.6(F_{cp2})
FA Type 3	80	20	160 (C_3)	40	600	0.484	96.8	54.3(F_{cp3})

Table 5- Equations to evaluate the reactivity of fly ash in terms of Pozzolonic Index

Pozzolonic Index (PI)= B/A		
$B = [1.598H_yC_c]-[kH_xC_c]-kV_w$	C_c= Volume of cement = (Mass/ Density)of cement = C_1/C_d C_d= Density of Cement	C_d=3.15 g/cm^3 C_c=152ml (480/3.15)
$A = kF_w/F_d-2.85F_w/S_d$	F_w= Weight of fly ash F_d= Density of fly ash S_d= Density of Sand	F_w= 40 g (20%) F_d= 2.15 g/cm^3 S_d=2.65 g/cm^3
Where, $k = [F_{cp}/(2.143*X)]^{1/3}$	F_{cp}= Compressive strength of cement mortar made with pozzolana	46.8 (F_{cp1}) 49.6(F_{cp2}) 54.3(F_{cp3})
$X = F_c/ [(2.145)*(Y/Z)^3]$ MPa	F_c= Compressive strength of cement mortar made with OPC	53.1(F_c)
$Y = 1.598*Cp*Hx$ ml (For pozzolanic cements)	C_p=Volume of pozzolanic cement =(Mass/ Density) of cement = C/C_d	C_p=67.8 ml(200/2.95) 2.95 Sp. gravity of pozzolanic cement
$Z= H_xC_p+V_w$ml	V_w= volume of water	V_w=290 ml W/C=0.484 (ASTM C 618) C=600 gm
Where, $H_x=(0.914W/C/(W/C+0.17)$ and $H_y=(0.914W/C_1)/(W/C_1+0.17)$	H_x= Percentage of hydrated cement H_y=Percentage of hydrated pozzolanic cement	W/C=0.484 (ASTM C 618) W/C_1=0.605 (290/480) H_x=0.676 H_y=0.714

Table 6 –Pozzolonic Indices (PI) of various fly ashes used in the study

F_c	53.1 MPa	Y	Z	$(Y/Z)^3$	X	k	B	A	PI =B /A
F_{cp1}	46.8 MPa	73.2	142.6	0.135	183.4	0.495	-0.02384	-0.10143	0.24
F_{cp2}	39.6 MPa	73.2	142.6	0.135	183.4	0.505	-0.02783	-0.10087	0.28
F_{cp3}	54.3 MPa	73.2	142.6	0.135	183.4	0.520	-0.03381	-0.10003	0.34

Table 7- Pozzolanic & Strength Activity Indexes of different fly ashes

Type of fly ash	PI	SAI
Type 1	0.24	88.1%
Type 2	0.28	93.4%
Type 3	0.34	102.3%

Sample Calculation:

H_x = (0.914*(135/360))/((135/360)+0.17)=0.63

Excess Lime/ Lime needed = (0.25*P_c*H_x)-(1.85*0.24*Pp) =16.64

% Excess Lime/ Lime needed= (Excess Lime/ Lime needed *100)/450=4%

Table 11 presents the mix quantities for various high volume fly ash concrete mixes and table 12 presents the compressive strengths of high volume fly ash concrete mixes made with various percentages of fly ash.

Table 8- Lime calculated for PI=0.24 (Type 1)

Total binder (Q) kg/m^3	% Cement	% FA	Cement (P_c) kg/m^3	Fly ash (P_p) kg/m^3	H_x	Excess Lime/ Lime needed kg/m^3	% Excess Lime/ Lime needed	Remarks
450	0.8	0.2	360	90	0.63	16.64	4	Excess
450	0.75	0.25	337.5	112.5	0.64	4.17	1	Excess
450	0.7	0.3	315	135	0.65	-8.40	-2	needed
450	0.65	0.35	292.5	157.5	0.67	-21.08	-5	needed
450	0.6	0.4	270	180	0.68	-33.88	-8	needed
450	0.55	0.45	247.5	202.5	0.70	-46.79	-10	needed
450	0.5	0.5	225	225	0.71	-59.84	-13	needed
450	0.45	0.55	202.5	247.5	0.73	-73.02	-16	needed
450	0.4	0.6	180	270	0.75	-86.35	-19	needed
450	0.35	0.65	157.5	292.5	0.76	-99.84	-22	needed
450	0.3	0.7	135	315	0.78	-113.49	-25	needed
450	0.25	0.75	112.5	337.5	0.80	-127.33	-28	needed
450	0.2	0.8	90	360	0.82	-141.37	-31	needed

Table 9 - Lime calculated for PI=0.28 (Type 2)

Total binder (Q) kg/m^3	% Cement	% FA	Cement (P_c) kg/m^3	Fly ash (P_p) kg/m^3	H_x	Excess Lime/ Lime needed kg/m^3	% Excess Lime/ Lime needed	Remarks
450	0.8	0.2	360	90	0.63	9.98	2	Excess
450	0.75	0.25	337.5	112.5	0.64	-4.16	-1	needed
450	0.7	0.3	315	135	0.65	-18.39	-4	needed
450	0.65	0.35	292.5	157.5	0.67	-32.74	-7	needed
450	0.6	0.4	270	180	0.68	-47.20	-10	needed
450	0.55	0.45	247.5	202.5	0.70	-61.78	-14	needed
450	0.5	0.5	225	225	0.71	-76.49	-17	needed
450	0.45	0.55	202.5	247.5	0.73	-91.34	-20	needed
450	0.4	0.6	180	270	0.75	-106.33	-24	needed
450	0.35	0.65	157.5	292.5	0.76	-121.48	-27	needed
450	0.3	0.7	135	315	0.78	-136.80	-30	needed
450	0.25	0.75	112.5	337.5	0.80	-152.31	-34	needed
450	0.2	0.8	90	360	0.82	-168.01	-37	needed

Table 10 - Lime calculated for PI=0.34 (Type 3)

Total binder (Q) kg/m^3	% Cement	% FA	Cement (P_c) kg/m^3	Fly ash (P_p) kg/m^3	H_x	Excess Lime/ Lime needed kg/m^3	% Excess Lime/ Lime needed	Remarks
450	0.8	0.2	360	90	0.63	-0.01	0	Not Required
450	0.75	0.25	337.5	112.5	0.64	-16.64	-4	needed
450	0.7	0.3	315	135	0.65	-33.38	-7	needed
450	0.65	0.35	292.5	157.5	0.67	-50.22	-11	needed
450	0.6	0.4	270	180	0.68	-67.18	-15	needed
450	0.55	0.45	247.5	202.5	0.70	-84.26	-19	needed
450	0.5	0.5	225	225	0.71	-101.46	-23	needed
450	0.45	0.55	202.5	247.5	0.73	-118.81	-26	needed
450	0.4	0.6	180	270	0.75	-136.30	-30	needed
450	0.35	0.65	157.5	292.5	0.76	-153.95	-34	needed
450	0.3	0.7	135	315	0.78	-171.77	-38	needed
450	0.25	0.75	112.5	337.5	0.80	-189.77	-42	needed
450	0.2	0.8	90	360	0.82	-207.97	-46	needed

Table 11 - Mix quantities of high volume fly ash concrete

Mix	Cement %	Fly ash %	Cement (kg/m^3)	Flyash (kg/m^3)	Water (kg/m^3)	Aggregate		SP (litre/m^3)
						Fine (kg/m^3)	Coarse (kg/m^3)	
Mix1(FA C0)	100	0	450	0.00	132	940	996	14
Mix2(FA C50)	50	50	225	225	132	940	996	14
Mix3(FA C60)	40	60	180	270	132	940	996	14
Mix4(FA C70)	30	70	135	315	132	940	996	14
Mix5(FA C80)	20	80	90	360	132	940	996	14

Table 12 - Compressive strengths of concrete mixes made with various percentages of fly ash

Type	Cement %	Fly ash %	Compressive Strength (MPa)		
			7 days	28 days	60days
Mix1(FAC0)	100	0	35.9	55.3	60.7
Mix2(FAC50)	50	50	13.4	33.5	39.3
Mix3(FAC60)	40	60	12.9	31.9	35.6
Mix4(FAC70)	30	70	10.7	22.1	32.9
Mix5(FAC80)	20	80	9.9	19.8	26.2

To enhance the early and later strengths, Silica Fume of 5 and 10% by weight of powder (Cement+ Fly ash) is used for the study.

Table 13- Mix quantities of high volume fly ash concrete with silica fume as additive

Mix	Powder		SF %bwp (Additive)	Cement (kg/m^3)	Flyash (kg/m^3)	Silica Fume (kg/m^3)	Water (kg/m^3)	Aggregate		SP (litre/m^3)
	Cement % bwp	Fly ash %bwp						Fine (kg/m^3)	Coarse (kg/m^3)	
Mix11(FAC0+SF5)	100	0	5	450	0	22.5	132	940	996	14
Mix12(FAC0+SF10)	100	0	10	450	0	45	132	940	996	14
Mix21(FAC50+SF5)	50	50	5	225	225	22.5	132	940	996	14
Mix21(FAC50+SF10)	50	50	10	225	225	45	132	940	996	14
Mix31(FAC60+SF5)	40	60	5	180	270	22.5	132	940	996	14
Mix32(FAC60+SF10)	40	60	10	180	270	45	132	940	996	14
Mix41(FAC70+SF5)	30	70	5	135	315	22.5	132	940	996	14
Mix42(FAC70+SF10)	30	70	10	135	315	45	132	940	996	14
Mix51(FAC80+SF5)	20	80	5	90	360	22.5	132	940	996	14
Mix52(FAC80+SF10)	20	80	10	90	360	45	132	940	996	14

Table 14- Compressive strengths of various fly ash based concrete mixes

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
Mix12(FAC0+SF10)	100	0	10	51.70	**79.63**	**87.41**
Mix21(FAC50+SF5)	50	50	5	16.08	20.2	27.16
Mix21(FAC50+SF10)	50	50	10	19.30	28.24	36.59
Mix31(FAC60+SF5)	40	60	5	15.48	28.28	32.72
Mix32(FAC60+SF10)	40	60	10	18.58	35.94	43.26
Mix41(FAC70+SF5)	30	70	5	12.84	26.52	39.48
Mix42(FAC70+SF10)	30	70	10	15.41	31.82	47.38
Mix51(FAC80+SF5)	20	80	5	11.88	23.76	31.44
Mix52(FAC80+SF10)	20	80	10	14.26	28.51	37.73

*%bwp-by weight of powder

Table 15- Compressive 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			7Days	28 Days	60 Days
Mix12(FAC0+SF10)	**100**	**0**	**10**	**-**	**41.70**	**69.63**	**77.41**
Mix21(FAC50+SF10)	50	50	10	0	19.30	28.24	36.59
Mix21(FAC50+SF10)	50	50	10	10	21.23	33.06	42.25
Mix21(FAC50+SF10)	50	50	10	20	23.35	48.37	58.47
Mix21(FAC50+SF10)	50	50	10	30	25.69	54.21	65.32
Mix21(FAC50+SF10)	50	50	10	40	28.26	50.63	52.85
Mix32(FAC60+SF10)	40	60	10	0	18.58	35.94	43.26
Mix32(FAC60+SF10)	40	60	10	10	20.44	50.53	58.59
Mix32(FAC60+SF10)	40	60	10	20	22.48	55.59	64.44
Mix32(FAC60+SF10)	40	60	10	30	24.73	61.15	70.89
Mix32(FAC60+SF10)	40	60	10	40	27.20	57.26	67.98
Mix42(FAC70+SF10)	30	70	10	0	15.41	31.82	47.38
Mix42(FAC70+SF10)	30	70	10	10	16.95	35.00	52.12
Mix42(FAC70+SF10)	30	70	10	20	18.65	38.50	57.33
Mix42(FAC70+SF10)	**30**	**70**	**10**	**30**	**40.51**	**82.35**	**83.06**
Mix42(FAC70+SF10)	30	70	10	40	22.56	46.59	69.37
Mix52(FAC80+SF10)	20	80	10	0	14.26	28.51	37.73
Mix52(FAC80+SF10)	20	80	10	10	15.69	31.36	41.50
Mix52(FAC80+SF10)	20	80	10	20	17.25	34.50	45.65
Mix52(FAC80+SF10)	20	80	10	30	28.98	57.95	70.22

Retrieval Number: C5927098319/2019©BEIESP
DOI:10.35940/ijrte.C5927.098319
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication

Mix52(FAC 80+SF10)	20	80	10	40	20.88	41.74	55.24

IV. DISCUSSIONS

Fly ash usage upto 40% in concrete may give high performance but gain of strength is very slow. If high volume of fly ash is intended to be used in concrete for cement replacement then strength is the major cause of concern. In the present study, high strength high volume fly ash concrete is developed with the high volume of fly ash about 70% replacement of cement. This mix achieved strength of 32.9 MPa. It is observed that as fly ash content increases beyond 50%, the compressive strength is reduced gradually. For M70 grade concrete, to achieve the desired strength silica fume is almost mandatory. In this study, silica fume of 5 and 10% by weight of powder (cement and fly ash) are used for study as additive to achieve the desired high strength. From table 14 it can be observed that for silica fume 10% and 100% OPC, the desired 70 MPa strength is achieved. But in high volume fly ash concrete mixes, high strengths could not be obtained due to unavailability of calcium hydroxide for pozzolanic action which is responsible for later strengths. Fly ash used for the study is chosen based on its reactivity of fly ash which can be evaluated in terms of pozzolonic indexes and strength activity indices. Hydraulic lime is added to high volume fly ash concrete made with silica fume to achieve the desired target strength. So based on the various trial and error combinations, it was found that concrete made with 70% fly ash with 10% silica fume and 30% lime as additives imparts high strength to high volume fly ash concrete.

V. CONCLUSIONS

Based on experiments conducted, the following observations are made-

1. High volume fly ash concrete is developed with 70% replacement of cement with fly ash.
2. Silica fume is used to enhance early strength and to achieve high strength. Silica fume of 10% by weight of powder is used as additive.
3. To achieve M70 grade strength, 30% lime by weight of powder is used as additive.
4. Quaternary blended concrete made with 70% fly ash + 30% cement by weight of powder content and with additives 10% silica fume and 30% lime attains high strength of 83.06 MPa.

REFERENCES

1. V Aggarwal, S Gupta, S Sachdeva (2012), 'High volume fly ash concrete: A Green concrete',J. of Env. Res. And Dev., vol. 6, no. 3A.
2. Antiohos, S Papageorgiou, A Papadakis, Tsimas S (2008), 'Influence of quicklime addition on the mechanical properties and hydration degree of blended cements containing different fly ashes', Const. and Build. Mat. vol. 22, Issue no. 6, pp. 1191-1200.
3. ASTM C 618-2003, "Standard specification for fly ash and raw calcined natural pozzolan for use as mineral admixture in portland cement concrete" C-618.
4. S Barbhuiya, J Gbagbo, M Russell, M and P S Basheer (2009), 'Properties of fly ash concrete modified with hydrated lime and silica fume', Const. and Build. Mat., Vol. 23, Issue no. 10, pp. 3233-3239.

AUTHORS PROFILE

Ms. Ch Mounika is student of Master of Technology (Structural Engineering)in Department of Civil Engineering at Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, India.

Dr. V Srinivasa Reddy is a Professor in Department of Civil Engineering at Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, India. He has nearly 100 publications in various journals and conferences. He has authored 3 Chapters and 2 Books in Civil Engineering.

Dr. M V Seshagiri Raois a Professor in Department of Civil Engineering at CVR College of Engineering, Hyderabad, India. He has nearly 200 publications in various journals and conferences. He has authored 5 Chapters and 4 Books in Civil Engineering.

Dr. S Shrihariis a Professor in Department of Civil Engineering atVJIT, Hyderabad, India. He has nearly 10 publications in various journals and conferences.