STRENGTH AND DURABILITY PROPERTIES OF HIGH VOLUME FLY ASH CONCRETE FOR M40 GRADE

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Abstract – *Use of fly ash in concrete is very beneficial in many ways, however in making of concrete is most suitable. In the following experimental analysis, optimum use of fly ash in replacement of Indian grade OPC-53 cement is determined while making of concrete.*

The aim was designing M40 grade of concrete using Indian standard IS 10262:2009 and replacing cement (OPC) with Fly Ash (class F) by 40%,50% and 60% (by weight) and then checking its compressive strength and flexure strength and durability of concrete by RCPT Test (ASTM). As in modern days, sustainable green material is requirement of the society this type of alternative material is a good solution. Cost benefit analysis is also included.

Key Words: **Concrete, Fly Ash, Superplasticiser, Sustainable, Durability, Pozzolanic, Chloride-ion, permeability, Gradation, Eco-friendly, Portland Cement.**

1. INTRODUCTION

In India, the disposal of bi-product of coal-based power plants such as fly ash has become a grievous problem. There will also be greater need to economies and to conserve the cement for more than one reasons. One of the vital solutions for utilization of fly ash as the cementitious material in replacement of OPC cement. High Volume Fly-Ash (HVFA) Concrete is a concrete in which, the cementitious(binder) material like cement is replaced by the fly-ash in higher proportion around 50% by weight.

Subsequent work has demonstrated that this type of concrete showed excellent mechanical and durability properties required for structural applications and pavement constructions. Some experimental investigations have also suggested the potential use of the high-volume fly ash system for concreting, light weight concrete and roller compacted concrete.

1.1 LITERATURE STUDY

The result shows that with increase in compressive strength results in increase in abrasion resistance. The study confirms that strength alone cannot be used to predict the abrasion of concrete mixtures with different porosity values.[1] The result shows that compressive strength of dense graded concrete is more than gap graded concrete. With increase in fly-ash content results in increase in compressive and flexure strength at later stage. With increase in fly-ash content is improving durability of concrete.[2] The test results show that concrete made with superplasticizer showed higher shrinkage than concrete made without superplasticizer. HVFA concrete become a possible alternative to OPC concrete used for road pavements application and large industrial floors.[3] The test results show that with increase in compressive strength results in increase in abrasion resistance.[4] The test results shows that with increase in fly ash content results in decrease in Dry shrinkage (micro strain). With increase in W/C ratio results increase in Dry shrinkage (micro strain) and with increase in fly ash content results in increase in abrasion loss and with increase in W/C ratio results in abrasion loss. [5] The result shows that with increase in compressive strength results in decrease in compressive strength. Drying Shrinkage is also decreasing with increases fly ash content. RCPT result shows that with increasing amount of fly ash content the rate of penetration of chlorides is decreasing. [6] Further increasing the Cementitious content more than 40% then there is strength in early stage (28 days) is less but later stage (90 days) is better. The study also concluded that with increasing fly ash content, the chloride penetration is less than a control concrete. [7]

2. MATERIAL

2.1 Fly Ash

Here we use fly ash as the mineral admixture in the HVFA concrete. The quality of fly ash is governed by IS 3812 - part II - 2013. High fineness, low carbon content, good reactivity is the essence of good fly ash. Fly ash is defined as “A finely divided residue that results from the combustion of ground or powdered coal and is transported from the combustion chamber by exhaust gases". [8] Fly ash is pozzolanic material.

The surplus lime released from cement hydration becomes the source of pozzolanic reactions. The balanced calcium hydroxide does not contribute to strength in major way. The fly ash present in mix chemically reacts with the balance calcium hydroxide and this secondary reaction leads to formation of secondary mineralogical phases, which has major contribution towards strength and durability of the hydrated product. Here, we use the fly ash which is produce from Wanakbori thermal power-plant in Kheda, Gujarat.

Specific Gravity of Fly ash = 2.2

2.2 Cement

Here we use OPC grade 53 cement which is conforming to IS 269:2015. Which is manufactured by Ultratech cement ltd.

Specific Gravity of Cement = 3.15

2.3 Aggregate (20 mm and 10 mm)

Here we use nominal size of aggregate is 20 mm (coarse aggregate) and 10 mm (grit) and sand. We know that the gradation aggregate is playing important role in gaining the strength of concrete. So, we perform the sieve analysis test on aggregate. Here we chose proportion of 20 mm and 10 mm aggregate by the theoretical analysis which gives 67% (20 mm) and 37% (10 mm) by absolute volume. Which gives results in stipulated limit given in IS 383:2016 as per Table No. 7 for combined gradation. All Aggregates are confirmed as prescribed Indian standard IS 383:2016.

Specific Gravity of Aggregate = 2.80

2.4 Admixture (Superplasticizer)

Here, we use BASF MasterGlenium SKY 8855 Superplasticizer. It is an admixture of a modern generation based on modified polycarboxylic ether. It is free of chloride and low alkali. It is compatible with all type of cements. It has new unique mechanism of action that greatly improves the effectiveness of cement dispersion. Admixture is prescribed as Indian standard IS 9103:2007 with all requirements.

Specific Gravity of Admixture = 1.1

2.5 Water

Here we use the potable water which is available at the college. Water is satisfying the Indian standard requirement as per IS 456:2000.

3. MIX DESIGN AS PER IS 10262:2009

Table -1: Mix Design of Concrete with % of Fly Ash Replacement

Material	0%(kg/m^3)	40%(kg/m^3)	50%(kg/m^3)	60%(kg/m^3)
Cement	394	260.04	216.7	173.36
Fly Ash	-	173.36	216.7	260.04
Water	157.6	157.6	157.6	157.6
Fine Aggregate (sand)	821.56	780.1	773.29	707.66
Coarse Aggregate (20 mm)	703.68	668.24	662.35	657.51
Coarse Aggregate (10 mm)	413.27	392.45	389.00	386.16
Admixture	2.758	3.0338	3.033	3.033
W/C ratio	0.4	0.3636	0.3636	0.3636

All specimen casted as per the condition prescribed in Indian standard IS:516-1956. Using Mechanical mixer.

4. TESTS ANS OBSERVATIONS

4.1 Slump Test

This test is performed as per prescribed Indian standard IS 1199-part I:2018. All standard dimensions of tools are used as specified by the standard.

All Slump value observed are under fall category. Which means concrete is very high workable.

4.2 Compression Test

This test is performed as per IS 516:1959. The cube specimen is of the size 15 x 15 x 15 cm is used for the largest nominal size of the aggregate does not exceed 20 mm, we test the cubes for various requires days.

4.3 Flexural Strength Test (2-Point load method)

This test is performed as per IS 516:1959. The specimen is use for this test is beam of 10 cm x 10 cm x 50 cm with 40 cm supporting span with two-point loading at equal distance from centre.

Table -2: Compressive Strength of Concrete Cubes

Strength (N/mm^2)	0 % Fly Ash	40 % Fly ash	50 % Fly ash	60 % Fly ash
After 3-days	41.63	19.62	15.26	8.72
	41.63	20.50	15.26	6.54
	39.89	20.00	15.70	7.84
After 7-days	44.69	28.34	22.67	22.67
	44.47	27.90	24.42	17.44
	50.35	28.34	23.54	20.22
After 28-days	60.19	48.39	40.11	35.75
	61.91	49.7	41.42	37.06
	63.22	49.27	42.30	39.67
After 56-days	62.35	53.192	44.47	37.06
	62.78	54.936	45.78	38.37
	63.22	56.68	47.088	39.24
After 90-days	62.78	54.5	48.396	49.7
	63.65	55.372	51.396	47.08
	64.092	56.372	53.192	48.40
After 180-days	62.35	58.62	54.68	50.37
	63.22	59.37	55.372	51.52
	63.65	62.18	58.00	52.06

Table -3: Flexural Strength of beams

Flexural Strength (N/mm^2)	0 % Fly Ash	40 % Fly ash	50 % Fly ash	60 % Fly ash
After 7-days	4.30	3.87	2.87	2.12
	4.36	3.96	2.89	2.52
	4.24	3.98	2.89	3.08
After 28-days	8.06	7.56	6.86	5.64
	8.50	7.60	6.92	5.94
	8.72	7.63	6.96	6.32

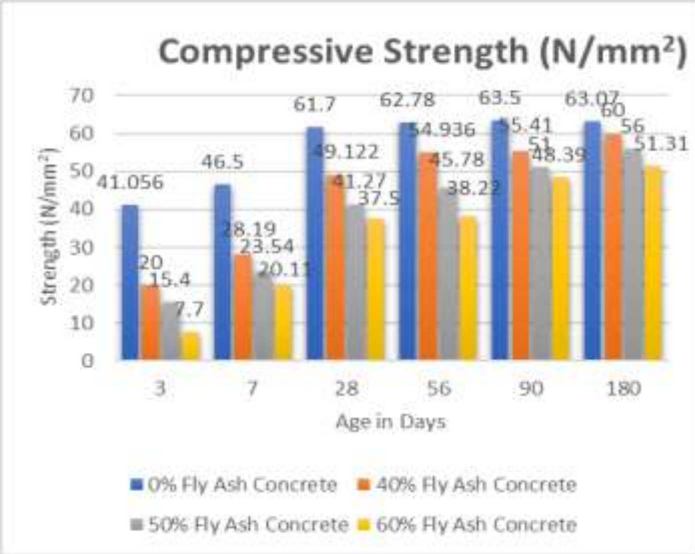

Fig.1-Compressive Strength Average of 3-specimen

4.4 Durability Test – Rapid Chloride Ion Permeability Test (RCPT-Test) as per ASTM C1202-12:

This test method covers the determination of the electrical conductance of concrete to provide rapid indication of its resistance to the penetration of chloride ions. [9] This test method is applicable to types of concrete where correlations have been established between this test procedure and long-term chloride ponding procedures such as those described in AASHTO T 259. [9]

This test method consists of monitoring the amount of electrical current passed through 50-mm thick slice of 100-mm nominal diameter cores or cylinders during a 6-h period. A potential different of 60 V DC is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in sodium hydroxide solution. The total charged passed, in coulombs, has been found to be related to the resistance of the specimen to chloride ion penetration. [9]

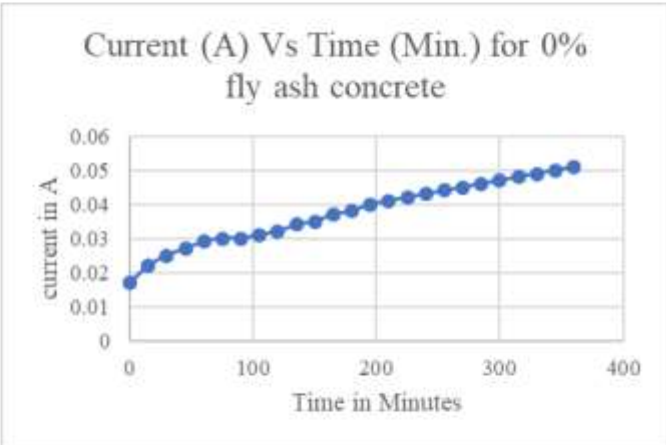

Fig.2- Current(A) Vs Time (Min.) For 0% Fly Ash Concrete

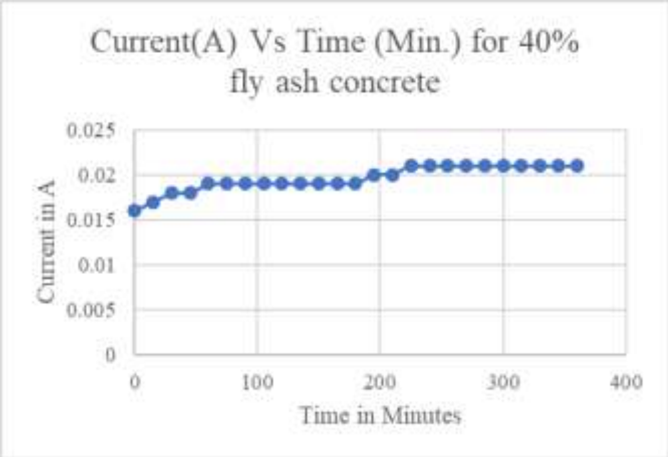

Fig.3- Current(A) Vs Time (Min.) For 40% Fly Ash Concrete

Table -4: RCPT test observations

0% Fly Ash	
Time(min)	Current(A)
0	0.017
15	0.022
30	0.025
45	0.027
60	0.029
75	0.030
90	0.030
105	0.031
120	0.032
135	0.034
150	0.035
165	0.037
180	0.038
195	0.040
210	0.041
225	0.042
240	0.043
255	0.044
270	0.045
285	0.046
300	0.047
315	0.048
330	0.049
345	0.050
360	0.051
∑ A =	**0.933**

40% Fly Ash	
Time(min)	Current(A)
0	0.016
15	0.017
30	0.018
45	0.018
60	0.019
75	0.019
90	0.019
105	0.019
120	0.019
135	0.019
150	0.019
165	0.019
180	0.019
195	0.020
210	0.020
225	0.021
240	0.021
255	0.021
270	0.021
285	0.021
300	0.021
315	0.021
330	0.021
345	0.021
360	0.021
∑ A =	**0.49**

1) For 0% fly ash concrete

Charge = 900 * $\sum A$

= 900 * 0.933

= 839.7 C

2) For 40% fly ash concrete

Charge (coulomb) = 900 * $\sum A$

= 900 * 0.49

= 441 C

Comment- very low permeability for both

As per Table X1.1 in ASTM C1202-12.

5. DISCUSSION AND COMPARISION WITH CODE

5.1 Compressive Strength

1) Only 40% fly ash concrete is achieved the target mean strength 48.25 N/mm^2 after the 28-days as per requirement of IS 456:2000.

2) Here, we observe that the after 28 days the compressive strength of 50% and 60% Fly Ash concrete are not gaining the target mean strength which is 48.25 N/mm^2 because the fly ash is react in later stage due to low reaction rate of fly ash and $Ca(OH)_2$. So, after the 90 days it gains the strength up to target mean strength.

5.2 Flexural Strength

- Minimum Flexure tensile strength required as per IS 456:2000 at 28-days of curing is,

$$f_{Cr} = 0.7\sqrt{f_{Ck}}$$

$= 4.86$ N/mm^2

- Here we observe that the flexural strength is as per the requirement of the IS 456:2000 for all the 0%, 40%, 50% and 60% Fly ash concrete is achieved.

5.3 Durability Test – Rapid Chloride Ion Permeability Test (RCPT-Test) as per ASTM C1202-12:

- Here we observe that the 0% fly ash concrete have chloride permeability is 839.7 C which is more than 40% fly ash concrete which have 441 C and which is nearly half of the 0% fly ash concrete that is due to the later stage reaction of fly ash with $Ca(OH)_2$.

Table 1. Chloride Permeability Based on Charge Passed

Charge Passed (coulombs)	Chloride Permeability	Typical of
> 4,000	High	High water-cement ratio (>0.6), PCC
2,000 - 4,000	Moderate	Moderate water-cement ratio (0.4 to 0.5), PCC
1,000 - 2,000	Low	Low water-cement ratio (<0.4), PCC
100 - 1,000	Very Low	Latex-modified concrete, silica-fume concrete
< 100	Negligible	Polymer impregnated concrete, polymer concrete

Fig.4- Table X1.1 as per ASTM C1202-12 [9]

6. COST BENEFIT ANALYSIS

Table -5: Cost benefit analysis

Material	Rate (₹/kg)	0% Fly ash		40% Fly ash	
		Qty.(kg)	Cost(₹)	Qty.(kg)	Cost(₹)
Cement	6.40	394.00	2521.6	260.04	1664.2
Fly ash	1.00	0.00	0.00	173.36	173.36
C.A. (20mm)	0.84	703.68	587.57	700.00	584.50

C.A. (10mm)	0.49	413.27	200.44	410.55	199.12
Sand	0.75	821.56	616.17	758.38	568.79
Admixture	195.0	2.58	502.71	3.03	591.59
Total in ₹/m^3			**4429**		**3782**

Note: The rate of material is as on date 11/02/2019 in India.

7. CONCLUSIONS

- We conclude that the compressive strength of 40% Fly ash concrete achieve the mean target strength (48.25 N/mm^2) at 28-days and this result is valid for following conditions only.
    1) Total cementitious content should be 433.33 kg/m^3
    2) W/C = 0.36
- Flexural strength of 40% Fly ash concrete is more than required as per IS 10262:2009.
- 40% Fly ash concrete is more durable than 0% Fly ash concrete.
- 40% Fly ash concrete is 15% less costly than 0% Fly ash concrete.

8. EXISTING APPLICATIONS OF HVFA CONCRETE

1) Hindu Temple, Hawaii with 57% Fly Ash Replacement [10]

   Monolith HVFA concrete foundation, designed for a service life of 1000 years.

Fig.5- Hindu Temple, Hawaii [10]

2) Foundation of BAPS Temple Chicago, USA. With 65% Fly Ash Replacement. [11]

   HVFA concrete was used for Unreinforced monolith

   Foundations and drilled piers for 1000-year life span

Fig.6- Foundation of BAPS Temple Chicago, USA. [11]

3) Utah State Capitol Building, USA. With 44% Fly ash replacement. [12]

Seismic Rehabilitation HVFA concrete was used for reinforced foundation, beams and shear walls.

Fig.7- Utah State Capitol Building, USA.[12]

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