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Influence of Fly Ash on Durability and Performance of Concrete

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Abstract: Concrete's durability and strength to sustain imposed loads makes it one of the most widely accepted building materials. The present trend in concrete technology is to increase both its strength and durability to meet the demands of the modern construction. Mineral admixtures like fly ash, ground granulated blast furnace slag, silica fume, etc are already investigated extensively by several researchers. This paper presents the result of an experimental investigation undertaken to study the durability characteristics of Ordinary Portland cement (OPC) concrete with and without fly ash. Fly ash is incorporated as a mineral admixture because of its advantageous properties like pozzolanic reaction and pore refinement. The concrete mix was designed as per IS 10262:2009 to yield M40 grade concrete, and the cement was replaced with 20% and 30% by weight of class f fly ash. Specimens were cast to test Compression strength, Rapid Chloride Permeability Test (RCPT), Water permeability test as per DIN standard and Water sorptivity test. The Compressive strength at early age (i.e. 7 days) for 20% replacement of fly ash was found to be 16.9% less than that of OPC concrete. But, 20% replacement of fly ash shows increase in strength when compared to OPC concrete at 28 days. The rapid chloride permeability test (RCPT) value of OPC concrete was found to be 1.85 times and 1.59 times more than that of 20% and 30% replacement of fly ash respectively at 28 days. The DIN water permeability test values of OPC concrete were found to be 1.7 times and 1.1 times more than that of 20% and 30% replacement levels of fly ash respectively at 28 days. From the current study it was found that replacement of fly ash content shows better durability and strength properties than that of OPC concrete.

Keywords: *Concrete, Fly ash, Compressive strength, Durability, Chloride permeability, Water sorptivity, Water permeability*

1. Introduction

The use of mineral admixtures such as fly ash, ground granulated blast – furnace slag, silica fume, etc as part of binders for concrete has been increasing throughout the world, particularly in the production of high strength and high performance concrete [1-3]. This is due to the potential ability of these materials to enhance the properties and performance of concrete through their filler effect, as well as pozzolanic reaction [4]. Most of the mineral admixtures are by-product materials; hence, their inclusion in concrete could serve as an effective means of disposal. Furthermore, their utilization as mineral admixtures to partially replace cement could somehow preserve the non-renewable resources required for the production of cement, and hence could somehow contribute to sustainable concrete construction. The inclusion of different mineral admixtures, can improve either or both the strength and durability properties of concrete. The resistance to chloride, water and air permeation is some of the simplest measures to determine the durability of concrete. The penetration of water, chloride and other aggressive ions into concrete primarily governs the physical and chemical process of deterioration [3, 4]. The microstructure of concrete mainly controls the physical/chemical phenomena associated with water movements and transport of ions in concrete.

Fly ash normally improves the workability of concrete, but the early-age strength was reported to be reduced [5, 6, 7]. This may be due to unhydrated fly ash in concrete which increases the porosity of the hardened cement paste at early age's results in a high permeable paste. The fly ash particles on reacting with calcium hydroxide, produces hydration products that decrease concrete porosity. Fly ash is used as fine granulates and upon hydration, becomes suitable for partially obstructing voids and pores [8, 9]. At later ages, the concrete mix which is replaced with fly ash exhibit greater strength development than control mix as the relative strength continues to increase with curing times [7]. There is a significant reduction in relative strength, with greater and consistent reduction at higher replacement levels of fly ash content [10]. At later ages, the concrete mix replaced with fly ash leads to decrease in coulombs charge passed, due to higher amount of pozzolano and proper particle size distribution resulting in lower permeability [10, 11]. At later ages, the concrete mix replaced with fly ash leads to decrease in capillary ingress of water than control mix [12].

It is seen from the literature that the mechanical and durability properties of fly ash concrete depends on the source and type of fly ash. Hence studies were taken upto investigated Class F fly ash from Ennore thermal power plant as partial replacement of cement. M40 grade concrete with replacement of Class F fly ash at 20% and 30% levels are investigated for their strength, permeation properties and chloride penetration resistance. Details of experimental investigation carried out and the results are discussed in this paper.

2. Experimental Work

2.1 Materials

All the materials used during this experimental programme comply with standard specifications. Ordinary Portland cement (OPC) 53 grade (Zuari Cement) confirming to IS 12269:1987 [13] has been used in this investigation. The cement of specific gravity 3.15is determined as per IS 4031 (part 11) 1988 [14] using Le-chatelier apparatus. Standard consistency of cement was found to be 31% which is determined as per IS 4031 (part 4) 1998 [15] using Vicat apparatus. Initial and final setting time for cement was found to be 160 minutes and 345 minutes respectively which is determined as per IS 4031 (part 5) 1998 [16]. Sand finer than 4.75 mm with specific gravity of 2.67 and fineness modulus 2.85 conforming to IS 383-1970 [17] was used as fine aggregate. The coarse aggregate of size 20 mm and 10 mm with specific gravity of 2.70, conforming to IS 383-1970 was used in this study. Fly ash is finely divided residue resulting from the combustion of powdered coal and transported by flue gases and collected by electrostatic precipitation. ASTM Class F fly ash with high silica content of specific gravity 2.05 obtained from Ennore thermal power plant was used in this experimental work. Super plasticizers conforming to ASTM C 494 Type F as a high range of water reducing admixture (Master Glenium Sky 8233) was used. Master Glenium Sky 8233 is an admixture of a new generation based on modified polycarboxylic ether. The product has been primarily developed for applications in high performance concrete where the highest durability and performance is required. This super plasticizer is free of chloride (i.e.) less than 0.2% and low alkali. It is a light brown liquid with relative density of 1.08 ± 0.01 at 25ºC and possesses pH content ≥ 6. In this experimental work, maximum amount of 0.5 % of total weight of cementitious material is added to attain desirable workability.

2.2 Mix Proportions

The materials are collected and mix proportions are to be obtained for M40 grade concrete. The final mix proportions were arrived at after having done many trials so as to have as slump between 50 and 180 mm at a constant water-binder ratio of 0.40. The slump was adjusted by adding different dosages of the super plasticizer. With all the above details mentioned in **2.1**, mix design confirming to IS 10262:2009 [18] is used and the mix design calculations were performed and the following mix proportions are summarized in table 1. Analysis was carried out in concrete mixtures with the levels of replacement of fly ash at 20% and 30% and comparative study is made with conventional concrete mix of M40 grade. The specimens were cast and tested to study the possibility of using fly ash as the substitute materials for cement in concrete.

Table 1: *Mix proportion used for the concrete*

Mix- Fly Ash (%)	Cement/ Fly Ash (Kg/m^3)	Fine Agg (Kg/m^3)	Coarse Agg (Kg/m^3)	Water (Kg/m^3)
CM-0%	395/0	798	1122	158
FA1-20%	315/80	782	1100	158
FA2-30%	275/120	775	1090	158

CM - Contol mix without fly ash.
FA 1- Specimen with 20% of fly ash.
FA 2- Specimen with 30% of fly ash.

2.3 Preparation of Specimens

The control mix using fly ash replaced as the cement was designed for cubes and cylinders and the specimen details are tabulated in table 2. The test specimen such as cubes of size 100x100x100 mm, 150x150x150mm and cylinders of size 100x200mm were cast to perform strength and durability test. The specimens were kept in mould for 24 hours at room temperature. After 24 hours, the specimens were demoulded and the water cured for 7 days and 28 days respectively. After 28 days of curing, the concrete cylinders were removed from the curing tank and sawed using water cooled diamond saw concrete cutter shown in figure 1. The cylinder of 100 mm diameter x 200 mm height was sawed to 100 mm diameter x 50 mm height. From the cast cylinder, the top 15 mm and bottom 35 mm was removed and the remaining portion of cylinder was sawed to the specimens of 50 mm thick, which is used for conducting Rapid Chloride ion Penetration test and water sorptivity test.

Table 2: *Specimen details*

Specimen	Size (mm)	Test carried out
Cube	100x100x100	Compressive strength
Cylinder disc	100x50	RCPT
Cylinder disc	100x50	Water sorptivity
Cube	150x150x150	DIN

Figure 1 *Diamond saw concrete cutter*

3. Experimental Test Procedures

3.1 Compressive Strength Test

Compressive strength test determines behavior of materials under compressive loads, the specimen is compressed and the maximum sustained load is recorded. In this study, the compressive strength test was performed on 100 mm cube specimens at the age of 7 and 28 days. Three specimens were tested at each testing age and average strength was reported. The compressive strength of concrete is determined as per IS 516:1959 [19] and the test set up is shown in figure2.

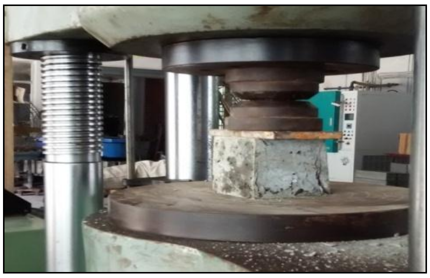

***Figure 2** Test setup to determine compressive strength*

3.2 Rapid Chloride Ion Penetration Test

The RCPT set-up followed the standard procedures described in ASTM C 1202 [20]. The RCPT is performed by monitoring the amount of electrical current passing through a sample (50 mm thick x 100 mm diameter) in 6 hours. A voltage of 60 V DC is maintained across the ends of the sample throughout the test. One lead is immersed in a sodium chloride solution (3 % by mass in distilled water) and the other in a sodium hydroxide solution (0.3 N in distilled water) as shown in figure 3. The total charge passed (Q) is calculated in coulombs by the following equation.

$$Q = 900 (I_0 + 2I_{30} + 2I_{60} + 2I_{90} + \ldots + 2I_{300} + 2I_{330} + I_{360})$$

Where,

Q = Charge passed (Coulombs)
I_0 = Current (amperes) immediately after voltage is applied
I_t= Current (amperes) at t minutes after voltage is applied.

***Figure 3** Test setup to determine chloride ion penetration*

The total charge passed, in coulombs, were found and related to the resistance of the specimen to chloride ion penetration. From table 3, based upon the charge passed the chloride ion permeability was found out.

***Table 3:** Charge passed through RCPT test as per ASTM C 1202*

S.NO.	Charges passed (coulombs)	Chloride ion Permeability
1	>4000	High
2	2000-4000	Moderate
3	1000-2000	Low
4	100-1000	Very low
5	<100	Negligible

3.3 Sorptivity Test

The methods of capillary absorption were adopted to determine the rate of absorption as well as the cumulative amount of water absorbed by different concrete specimens. The sorptivity tests were done on a concrete disc specimen of 100 mm diameter and 50 mm thickness as per ASTM C 1585 [21]. After 28 days the specimens were taken from curing tank and the specimens were dried in oven at 110°Cfor 24hrs.

The specimens were coated with epoxy on the curved surface so as to allow water ingress into concrete only from the bottom surface. The specimens were weighed and the one face was placed in contact with water. The schematic arrangement of the sorptivity test is shown in figure 4.

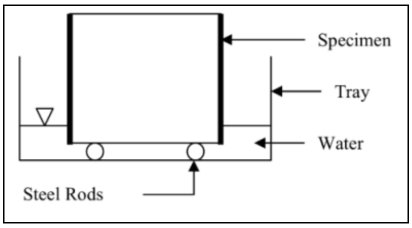

***Figure 4** Schematic diagram of sorptivity test*

The specimens were immersed in a tray containing water on 8mm diameter steel rebars to allow free access of water to inflow. The water level was maintained at 5mm above the base of the specimen as shown in the figure 5. Immediately after the immersion of the specimen into water, the start time of the test were recorded. The gain in weight due to water absorption was measured after mopping of with a dry tissue at suitable intervals up to 6hrs. The sorptivity value was calculated by the formulae.

$$\frac{mt}{a*d} = I$$

Where,

I = the absorption
m_t = the change in specimen mass in grams, at the time t
a = the exposed area of the specimen, in mm^2
d = the density of the water in g/mm^3

Figure 5 *Test setup to determine capillary ingress of water*

3.4 DIN Water Permeability Test

Deutsches Institute Fur Normung (DIN) water permeability test is performed as per DIN 1048using 150 x 150 x 150 mm cubes. This test is conducted by applying constant 5 bar water pressure on cube specimen for 3 days. After 3 days, the pressure is released and cube is splitted to 2 halves, the depth of water penetration (in mm) is recorded. The test setup to determine the depth of water penetration is shown in figure 6.

Figure 6 *Test setup to determine the depth of Water penetration*

4. Results and Discussion

4.1 Compressive Strength

The compressive strength test results at various replacement levels of fly ash content are tabulated in table 4.

Table 4: *Concrete compression test results at 7th and 28th day*

Mix	Fly ash (%)	7th DAY (MPa)	28th DAY (MPa)
CM	0	43.94	55.80
FA1	20	36.50	56.60
FA2	30	33.29	51.75

The compressive strength result of FA1 was found to be decreased at the age of 7th day than CM. This can be attributed to the slower rate of pozzolanic reaction between fly ash and lime generated by the OPC hydration. At 28thday, FA1 exhibit greater strength development than the CM as the relative strength continues to increase with curing times. This is in aggrement with the findings of Megat Johari et al [7].

The compressive strength result of FA2 was found to be decreased at the age of 7th and 28th day when compared with CM. There is a significant reduction in relative strength, with greater and consistent reduction at higher replacement levels of fly ash content. This is in aggrement with the findings of Prabakar et al [10].

4.2 Rapid Chloride Permeability Test

The Rapid Chloride Permeability Test (RCPT) results at various replacement levels of fly ash content are tabulated in table 5.

Table 5: *RCPT test results at 28th day*

Mix	Fly Ash (%)	Charge passed (coulombs)	Chloride penetration as per ASTMC 1202
CM	0	1110	Low
FA1	20	600	Very low
FA2	30	490	Very low

It is inferred from table 5 that only the control concrete has low chloride ion penetrability at the age of 28th day. Whereas for all other replacement levels the results shows very low chloride ion penetrability at the 28th day of age.

Comparison of CM with FA1 and FA2 shows that incorporation of 20% and 30% fly ash leads to decrease in coulombs charge passed through the standard sample at 28th day. This is due to higher amount of pozzolano and proper particle size distribution resulting in lower permeability.This is in aggrement with the findings of Prabakar et al [10] and Yatin H Patel [11].

4.3 Water Sorptivity Test

The sorptivity test results at various replacement levels of fly ash content are tabulated in table 6.

Table 6: *Sorptivity test results at 28th day*

Mix	Fly ash (%)	Initial rate of absorption ($x10^{-3}mm/\sqrt{s}$)
CM	0	5.13
FA1	20	4.90
FA2	30	3.72

Considering the effect of FA1 and FA2 when compared with CM on the sorptivity of the samples, it is evident that for FA1 and FA2 the sorptivity of the sample decreases than CM at 28th day. This is in aggrement with the findings of Elahi et al [12].

From the comparative study of sorptivity values, it is clearly visible that there is decrease in sorptivity with age of sample as well as with increase in the replacement of fly ash content at 28 days of age which is as expected. This is due to the fact that the pores become finer with increase in age of the samples.

4.4 DIN Water Permeability Test

The DIN (Deutsches Institute Fur Normung) test results at various fly ash replacements are tabulated in table 7.

Table 7: *DIN water permeability test results at 28th day*

Mix	Fly ash (%)	Depth of water penetration(mm)
CM	0	15.25
FA1	20	8.83
FA2	30	13.84

From table 7, it is clearly visible that the concrete specimens with 20% replacement of fly ash shows less depth of water penetration when compared to other two concrete mixes. As per DIN 1048, the depth of water penetration (mm) into the concrete specimen for various levels of fly ash replacements are evaluated by applying standard 5 bar pressure on the concrete specimens for 3 days.

From the results obtained it is inferred that 20% replacement of fly ash has better durability property than the other replacement levels.

5. Conclusions

Based on the experimental study carried out, the following conclusions can be made.

1) The specimen with only 20% replacement of fly ash shows good results in compressive strength at 28 days when compared to control mix. However the 7 days strength was found to be decreased at both 20% and 30% fly ash replacements compared to control mix.
2) The concrete with the 20% and 30% replacement of fly ash shows less permeability to chloride ions than control mix.
3) The initial rate of water sorption and the depth of water penetration with the replacement of 20% and 30% fly ash were found to be improved when compared to the control mix.
4) From this study it is inferred that the fly ash can be used as a sustainable construction material when replaced in 20% as it shows better strength and durability properties.

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References

[1] Aitcin P.C. – "High performance concrete", E & FN Spon; pp. 591, 1998.

[2] Malhotra V.M. and Mehta P.K. – "Pozzolanic and cementitious materials", Advances in concrete technology, vol. 1, Gordon and Breach Publishers; pp. 191, 1996.

[3] Mehta P.K. and Aitcin P.C. – "Micro-structural basis of selection of materials and mix proportions for high-strength concrete", American Concrete Institute, ACI SP 121, pp. 265-286, 1990.

[4] Mehta P.K. and Monteiro P.J.M. – "Concrete – microstructure properties and materials", 3rd ed., Mc Graw-Hill, pp. 659, 2006.

[5] Mora E.P., Paya J. and Monzo J. – "Influence of different sized fraction of a fly ash on workability of mortars", Cement and concrete research, vol. 23, pp. 917-924, 1993.

[6] Chindaprasirt P., Jaturapitakkul C. and Sinsiri T., - "Effect of fly ash fineness on compressive strength and pore size of blended cement paste", Cement and concrete composite, vol.27, pp. 425-428, 2005.

[7] Megat Johari M.A., Brooks J.J., Shahid Kabir, Patrice Rivard - "Influence of supplementary cementitious materials on engineering properties of high strength concrete", Construction and building materials, vol. 25, pp. 2639 – 2648, 2011.

[8] Ergodu K. and Turker P. – "Effect of fly ash particle size on compressive strength of Portland cement fly ash mortars", Cement and concrete research, vol. 28, pp. 1217-1222, 1998.

[9] Bharatkumar B.H., Narayanan R., Raghuprasad B.K, and Ramachandramurthy D.S. -"Mix proportioning of high performance concrete", Cement and Concrete composites, vol. 23, pp. 71-80, 2001.

[10] Prabakar J., Devadas Manoharan P. and Neelamegam M. –"Effect of fly ash on durability and performance of concrete", Indian Concrete Journal, vol. 85, pp. 9-15, 2011.

[11] Yatin H Patel., Prof. Jignesh M Patel, Dr. H S Patel –"Study on durability of high performance concrete with alccofine and fly ash", vol. 2, Issue 3, pp. 154 – 157, 2013.

[12] Elahi A., Basheer P.A.M., Nanukuttan S.V., Khan Q.U.Z – "Mechanical and durability properties of high performance concretes containing supplementary cementitious materials", Construction and building materials , vol. 24 , pp. 292 – 299, 2010.

[13] IS 12269-1987, "Specification for 53 grades Ordinary Portland cement".

[14] IS 4031 (part 11) – 1988, "Methods of physical tests for hydraulic cement part 11 Determination of density".

[15] IS 4031 (part 4) – 1988, "Indian standard methods of physical tests for hydraulic cement part 4 Determination of consistency of standard cement paste".

[16] IS 4031 (part 5) – 1988, “Methods of physical tests for hydraulic cement part 5 Determination of initial and final setting times”.
[17] IS 383:1970, “Specification for coarse and fine aggregates from natural sources for concrete”.
[18] IS 10262:2009, Indian Standard – Concrete Mix Proportioning – Guidelines.
[19] IS 516:1959, “Indian Standard methods of tests for strength of concrete”.
[20] ASTM C 1202-12, “Standard test method for electrical indication of concrete’s ability to resist chloride ion penetration”.
[21] ASTM C 1585-13, “Standard test method for measurement of rate of absorption of water by hydraulic cement concretes”.