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Durability Assessment of Concrete with Class-F Fly Ash by Chloride Ion Permeability

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Abstract*: This paper discusses on Rapid Chloride Permeability Test investigations on penetration of chloride ions included with replacement of cement by flyash material. By weigth of cement, the fly ash content is replaced from 0% to 60%. Concrete mixes with different binder content varies from 350, 400 and 450 kg/m^3 were proportioned with different water binder(w/b) ratios = 0.4, 0.45 and 0.50. Specimens were casted and tested for 28 days. For all the combinations, RCPT was carried out and the charge passed through the specimens was noted. Rapid Chloride Permeability Test value of concrete without fly ash was found to be more than the concrete with fly ash. The Rapid Chloride Permeability Test values are found to be decreased if the percentage of flyash increases. The reason could be the pozzolanic reaction products (CSH) fill the pores between the cement pastes and cause a denser concrete matrix, resulting in better durability. Hence, it can be suggested that the fly ash concrete up to 50% replacement can be used for variety of applications.

Keywords: Fly ash concrete, Pozzolanic material, Rapid Chloride Permeability Test (RCPT).

I. INTRODUCTION

The concrete usage in the construction is started from the olden days of civilization. Concrete construction consumes a lot of materials like coarse aggregate and fine aggregate and the principal raw material of concrete i.e. cement clinker is responsible for greenhouse gas (GHG) effect" accounting for 10% of global anthropogenic CO_2.The fly ash is obtained as an unusable product from the coal burning power plants, to avoid the discarding problem of fly ash. It is used to replace the fly ash percentage by its cement content weight in concrete and the replacement is in between the 10% to 50% of fly ash in cement content. Fly ash is used as a pozzolanic mineral in concrete, the cement is partially replaced by mineral products such as silica fume, including coal fly ash, and slag can reduce the Co_2 emission in manufacturing process of cement. A significant development in this direction has already been in the use and acceptance of Supplementary cementing materials (SCM). Use of SCM up to some extent will be fine and may not be adequate if the targets are different, for example maximum reduction of CO_2 emission and its sustainability.

One type of fly ash is Class – C, it is having high calcium content which is having more than 20% Cao and other class F fly ash is also containing less amount of calcium which is less than class C. In this experiment, class F fly ash is replaced in the concrete at 0% to 60% levels were used for the rapid chloride permeability test. It is very well known that any concrete has to qualify two aspects, namely, mechanical properties and durability properties in order to use for structural applications.The concrete capacity to Resist Chloride Penetration is an important factor in determining its good performance over an extended period. The resistance to penetrate of chloride ions is determined by RCPT. The amount of electrical charge passed through concrete for a specified time is monitored by this test. RCPT `determines the electrical conductance of the different grades of concrete.

II. LITERATURE REVIEW

V Seshaseyee et al. [1] studied on durability properties like Compressive Strength, RCPT and Water Sorptivity test. The RCPT value of OPC concrete was found to be 1.85 times and 2.26 times more than that of 20% and 30% replacement of cement with flyash. *Amrutha et al.* [2] represents the results of this experimental study on Durablity on HVFAC. The result shows that the HVFAC mixes should have less permeability than the normal vibrate concrete mixes. *R. Dharmaraj*[1], *R. Malathy*[2] [3] studied the RCPT for durability studies on corrosion inhibiting self – compacting concrete. The results reveal that the fly ash concrete mixes would have lesser permeable voids than the conventional concrete mixes. *Ozkan Sengul*[1]*and Mehmet Ali Tasdemir*[2] [4] investigate the Compressive Strength and Rapid Chloride permeability of concrete with ground fly ash and slag. The test results represents the ground flyash reduce the rapid chloride permeability of concrete. *Pandurangan et al.* [5] studied the performance of concretes with zero percentage and 55%, 62%, 75% and 85% of HVFAC. The RCPT, Compressive, Impact and Flexural Strengths in all mixes were determined. It shows that the resistance of corrosion is greater in high volume fly ash concrete by penetration of chloride ions, which is low in HVFAC. *Rashad* [6] reported on fly ash of class F and studies on drying shrinkage, absorption resistance, water absorption, porosity and thermal properties of high volume flyash concrete. Mehta studied on sustainable development on concrete. Replacement of 50% flyash in concrete, water demand is reduced and better durability opposed to sulphate attacks. *Jelena et al*. [7]

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investigated on HVFAC and their role insustainable development. 30% fly ash replaced with cement improved durability and porosity, while more than 30% of fly ash replacement reduces the pressure of water and upgrade the durability in later ages. *A. Parvathy Karthika, V.Gayathri* [8] experimental studies show that durability tests includes with rapid chloride permeability test and water absorption test. Durability of concrete with flyash compared with nominal mix of concrete is improved.

III. EXPERIMENTAL PROGRAM

A.Materials

In this study 53 grade of Ordinary Portland Cement (OPC) is used. Tests on cement were carried out and results are given in Table 1. Chemical composition of fly ash is given in Table 2. The fine aggregate was natural sand having a nominal size of 4.75 mm. 20mm and 12mm size of coarse aggregates are used. A test on Aggregates as per code IS: 383-1970 [11] and their properties of aggregates are presented in Table 3.

B. Mix Proportions

Concrete mixes having binder contents of 350, 400 and 450kg/m^3 were casted. Fly ash of class F was used to replace the cement. Fly ash cement varies from 0 to 60% at 10% intervals. Water binder ratio used for mixes are 0.4, 0.45 and 0.5. The coarse aggregates consist of combination of 20mm and 12mm size. The proportions of mixes of material quantities for different concrete mixes are tabulated in table 4.

Table 1 Physical Properties of OPC

Physical property	Value
Fineness	8.0
Specific surface m^2/kg	279
Normal consistency (%)	29
Setting timings (min)	
Initial	90
Final	210
Compressive Strength (MPa)	
28 days	56.8
Specific Gravity	3.20

Table 2 Chemical Composition of Fly Ash

Parameter	%	As per ASTM C618 [10]
Silicon dioxide	60.76	--
Aluminum oxide	31.7	--
Ferric oxide	3.5	--
Silicon dioxide+ Aluminum oxide+ Ferric oxide	95.96	70.0 min
Titanium Oxide	1.762	----
Potassium Oxide	1.074	----
Calcium Oxide	0.768	----
Phosphorus pentoxide	0.164	---
Zirconium Dioxide	0.052	---
Manganese Oxide	0.029	---
Loss on Ignition	2.5	6.0 max
Moisture	0.6	3.0 max

Table 3 Physical Properties of Aggregates

Property	Fine Aggregate	Coarse Aggregate
Specific gravity	2.67	2.71
Fineness modulus	2.35	6.4
Unit weight (kg/m^3)	1700	1650

C. Preparation of specimen

The concrete specimens are made using standard moulds of 100mm diameter x 200mm height. After curing the concrete samples are cut in 50mm thick specimen using circular saw cutting machine.

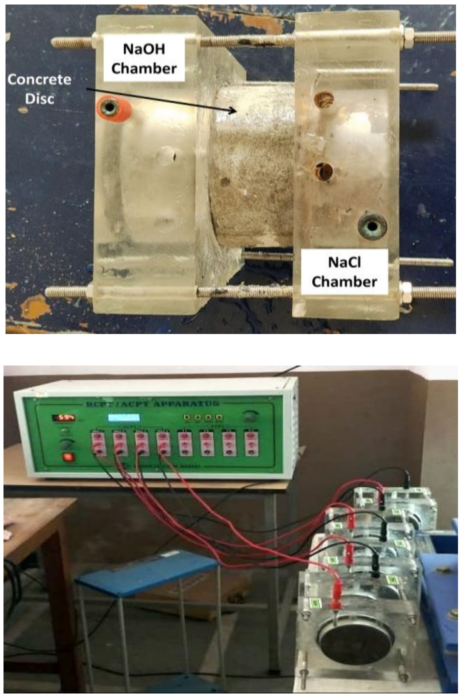

Fig. 1. Typical test setup for RCPT

D. Preparation of solutions

The diffuser cell consists of two chambers. One chamber is filled with sodium chloride (NaCl) and another sodium hydroxide solution is filled. The strength of sodium chloride solution is 3% and the strength of sodium hydroxide solution is 0.3M.

Na sodium - 22.989
O oxygen – 15.999
H hydrogen – 1.0079

To make 3% solution of NaCl.30 grams of salt is mixed with 1000ml of distilled water. To make molar 0.3M NaOH solution. 0.3x40gms = 12gms of NaOH is dissolved with 1000ml of distilled water.

Table 4 Various Mix Proportions Of Fly Ash-Based Concrete

Mix	% Replacement of cement by flyash	Cement (kg/m^3)	Fly ash (FA) (kg/m3)	Water (kg/m^3)	Water to binder (w/b) ratio
MIX350 FA00 0.40	0	350	0	140	0.4
MIX350 FA10 0.40	10	315	35		
MIX350 FA20 0.40	20	280	70		
MIX350 FA30 0.40	30	245	105		
MIX350 FA40 0.40	40	210	140		
MIX350 FA50 0.40	50	175	175		
MIX350 FA60 0.40	60	140	210		
MIX350 FA00 0.45	0	350	0	158	0.45
MIX350 FA10 0.45	10	315	35		
MIX350 FA20 0.45	20	280	70		
MIX350 FA30 0.45	30	245	105		
MIX350 FA40 0.45	40	210	140		
MIX350 FA50 0.45	50	175	175		
MIX350 FA60 0.45	60	140	210		
MIX350-FA00-0.5	0	350	0	175	0.5
MIX350 FA10 0.5	10	315	35		
MIX350 FA20 0.5	20	280	70		
MIX350 FA30 0.5	30	245	105		
MIX350 FA40 0.5	40	210	140		
MIX350 FA50 0.5	50	175	175		
MIX350 FA60 0.5	60	140	210		
MIX400 FA00 0.4	0	400	0	160	0.4
MIX400 FA10 0.4	10	360	40		
MIX400 FA20 0.4	20	320	80		
MIX400 FA30 0.4	30	280	120		
MIX400 FA40 0.4	40	240	160		
MIX400 FA50 0.4	50	200	200		
MIX400 FA60 0.4	60	160	240		
MIX400 FA00 0.45	0	400	0	180	0.45
MIX400 FA10 0.45	10	360	40		
MIX400 FA20 0.45	20	320	80		
MIX400 FA30 0.45	30	280	120		
MIX400 FA40 0.45	40	240	160		
MIX400 FA50 0.45	50	200	200		
MIX400 FA60 0.45	60	160	240		
MIX400 FA00 0.5	0	400	0	200	0.5
MIX400 FA10 0.5	10	360	40		
MIX400 FA20 0.5	20	320	80		
MIX400 FA30 0.5	30	280	120		
MIX400 FA40 0.5	40	240	160		
MIX400 FA50 0.5	50	200	200		
MIX400 FA60 0.5	60	160	240		
MIX450 FA00 0.4	0	450	0	180	0.4
MIX450 FA10 0.4	10	405	45		
MIX450 FA20 0.4	20	360	90		
MIX450 FA30 0.4	30	315	135		
MIX450 FA40 0.4	40	270	180		
MIX450 FA50 0.4	50	225	225		
MIX450 FA60 0.4	60	180	270		

MIX450 FA00 0.45	0	450	0		
MIX450 FA10 0.45	10	405	45		
MIX450 FA20 0.45	20	360	90		
MIX450 FA30 0.45	30	315	135	203	0.45
MIX450 FA40 0.45	40	270	180		
MIX450 FA50 0.45	50	225	225		
MIX450 FA60 0.45	60	180	270		
MIX450 FA00 0.5	0	450	0		
MIX450 FA10 0.5	10	405	45		
MIX450 FA20 0.5	20	360	90		
MIX450 FA30 0.5	30	315	135	225	0.5
MIX450 FA40 0.5	40	270	180		
MIX450 FA50 0.5	50	225	225		
MIX450 FA60 0.5	60	180	270		

E. Procedure

The specimen was fixed in between the halves of the test cell. One cell is overfilled with of 3% NaCl solution which is attached to power supply of negative terminal and the further side is loaded with 0.3M NaOH solutions which are attached to the power supply of positive terminal. These test cells are sealed together by the boundaries of specimen and cell with the help of sealant. Wires are attached to the cell. Turn on power supply, set the voltage into 60V, and initial reading is recorded as I_0, Record the reading at every 30 min up to 6 hours. Each cell contains appropriate solution must remained in the whole period of the test.

F. Calculation:

The following formula described in ASTM-C 1202 [9]

$$Q = 900\,(I_0 + 2I_{30} + 2I_{60} + \ldots + 2I_{330} + I_{360}) \quad (1)$$

Where,

Q = Charge passed (Coulombs),

I_0, I_{30}, I_{60}...I_{330}, I_{360} = Current in amperes at 0, 30, 60....330, 360 minutes respectively.

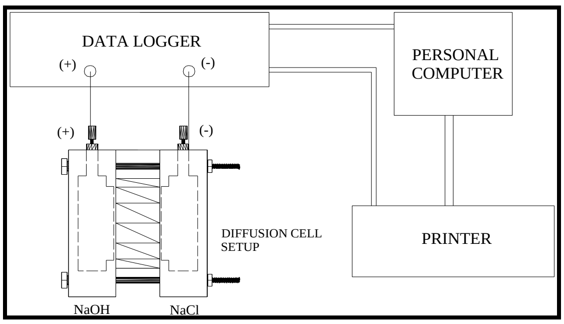

Fig.2. Typical layout of Diffusion and RCPT Experiment Unit

Table 5 Ratings of Chloride Permeability from the code [9]

Charge Passed (Coulombs)	Chloride Ion Penetrability
<100	Negligible
100-1000	Very Low
1000 – 2000	Low
2000-4000	Moderate
>4000	High

Table 6 RCPT results for various mixes of fly ash incorporated Concrete

Mix	Charge passed in Coulombs		
	W/b =0.4	W/b =0.45	W/b = 0.5
MIX350 FA00	1407	1492	1501
MIX350 FA10	1287	1362	1411
MIX350 FA20	1178	1222	1233
MIX350 FA30	1169	1152	1192
MIX350 FA40	1166	1089	1083
MIX350 FA50	1124	1059	1071
MIX350 FA60	1111	1053	1052
MIX400 FA00	1372	1437	1461
MIX400 FA10	1288	1333	1373
MIX400 FA20	1206	1222	1246
MIX400 FA30	1184	1177	1206
MIX400 FA40	1176	1137	1132
MIX400 FA50	1152	1118	1121
MIX400 FA60	1139	1098	1093
MIX450 FA00	1338	1382	1421
MIX450 FA10	1290	1305	1335
MIX450 FA20	1235	1222	1258
MIX450 FA30	1200	1201	1221
MIX450 FA40	1186	1184	1180
MIX450 FA50	1181	1178	1170
MIX450 FA60	1168	1143	1134

IV. RESULTS AND DISCUSSION

The Rapid Chloride Permeability Test (RCPT) results at various replacement of cement with fly ash (FA) content and with different Water binder (W/b) ratio and with different binder contents are tabulated in table – 6 fig. 3 shows the variation of RCPT values for the mixes having binder content 350 kg/m^3 and W/b = 0.40, 0.45 and 0.50 and varying fly ash content from 0 to 60%. The RCPT values are decreases in FA concrete when it is compared with the controlled concrete mix. The value of RCPT of mix 350 kg/m^3 at 0% fly ash content is 1407.6 and at 60% of fly ash content is 1111.5.

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The percentage decrease of RCPT values are more in 0 to 30% of fly ash content and in between 30% to 60% FA content, the percentage of decrease is less. However, the values of RCPT are decreases more than 21% in 60% of fly ash concrete when compared with the concrete without FA. However, if water binder ratio increases for the same binder content, the RCPT value increases. The value of RCPT of mixes with w/b = 0.5 increases about 6.2% when compared with mixer, with w/b = 0.4 for the same binder content of 350 kg/m^3.

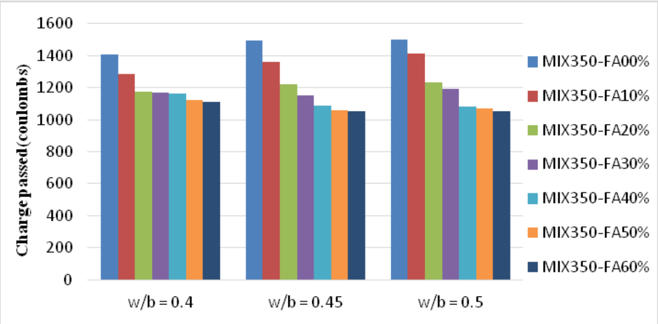

Fig.3. RCPT test results of binder content 350kg/m^3 and with W/b ratios of 0.4, 0.45 and 0.5

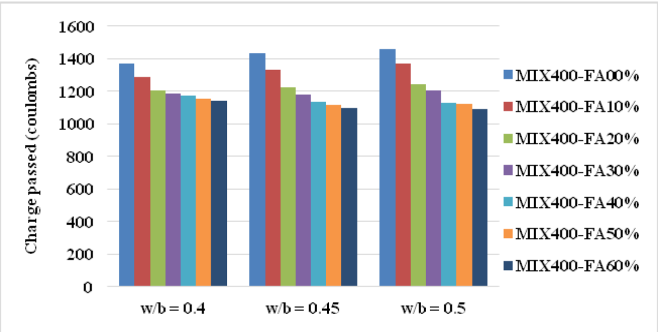

Fig.4. RCPT test results of binder content 400kg/m^3 and with W/b ratios of 0.40, 0.45 and 0.50

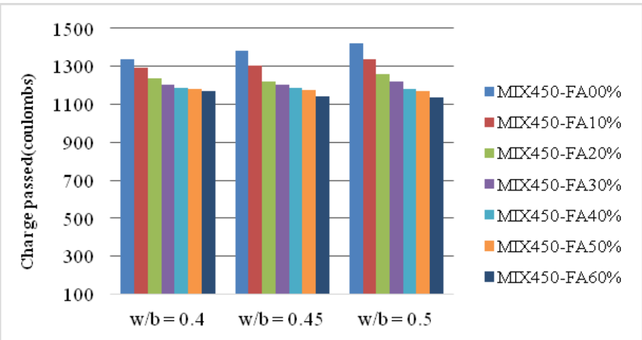

Fig.5. RCPT test results of binder content 450kg/m^3 and with W/b ratios of 0.40, 0.45 and 0.50

fig. 4 shows the variation of RCPT values for the mixes having binder content 400 kg/m^3 and w/b = 0.40, 0.45 and 0.50 and varying fly ash content from 0 to 60%. The RCPT values are decreases in FA concrete, which is compared with controlled concrete. The value of RCPT of mix 400 kg/m^3 at 0% fly ash content is 1372.95 and at 60% of fly ash content of concrete is 1139.85. The percentage decrease of RCPT values are more in 0 to 30% content of fly ash and in between 30% to 60% content of fly ash, the percentage of decrease is less. However, the values of RCPT are decreases more than 16.9% in 60% of fly ash concrete when it is compared with the mix of concrete without FA. However, if water binder ratio increases for the same binder content, the RCPT value increases. The value of RCPT of mixes with 0.50 W/b increases about 6% when compared with mixer, with 0.40 W/b for the same binder content of 400kg/m^3.

fig. 5 shows the variation of RCPT values for the mixes having 450 kg/m^3 binder content and w/b = 0.40, 0.45 and 0.5and varying content from 0 to 60% fly ash. The RCPT values are decreases in FA concrete which is compared with concrete without FA. The value of RCPT of mixes 450kg/m^3 at 0% fly ash is 1338.3 and at 60% of fly ash is 1168.2. The percentage decrease of RCPT values are more in 0 to 30% of fly ash content and in between 30% to 60% fly ash content, the percentage of decrease is less. However, the values of RCPT are decreases more than 12% in 60% of fly ash concrete when compared with the mix of concrete without FA. However, if water binder ratio increases for the same binder content, the RCPT value increases. The value of RCPT of mixes with 0.5 water binder ratio increases about 5.8% and it is compared with mixer, with 0.4 water binder ratio for the same binder content of 450kg/m^3.

Figures 3 to 5, it can be noted that

- For the controlled concrete (without fly ash), keeping cement content is fixed, RCPT increases with increase of water cement ratio. For example, for cement content 350 kg/m^3, the RCPT values are 1407, 1492 and 1501 respectively for water cement ratios 0.4, 0.45 and 0.5. With the increase of cement content (from 350 kg/m^3 to 450 kg/m^3), the RCPT values are decreasing. The reason could be due to more CSH formation and less voids.
- For a particular cement quantity and water binder ratio (example, 350 kg/m^3 and w/b = 0.4), with the increase of replacement of cement by fly ash, RCPT values are decreasing compared to controlled concrete. Same result has been realized for all water binder ratios.

Summary

In view of this, the most important durability test, namely Rapid chloride permeability tests was carried out on several FA incorporated concrete mixes. The mixes include 350, 400 and 450 kg/m^3 with w/b = 0.40, 0.45 and 0.50. In each mix, cement is replaced by FA in increments of 10% up to maximum of 60%. It has been observed that for a particular cement quantity and water binder ratio (example, 350 kg/m^3 and w/b = 0.4), with increase of fly ash which is replaced by cement, RCPT values are decreasing compared to controlled concrete and the same result has been realized for all water binder ratios. The pozzolanic reaction products fill the holes between the cement pastes and cause a denser concrete structure, resulting in better durability behaviour of the concrete. The investigations reported in this paper; shows that high - volume fly ash concrete have excellent durability characteristics with regard to rapid chloride penetration.

V. CONCLUSIONS

1. RCPT value decreases with the increase of % of fly ash replaced with cement compared with the concrete without fly ash.
2. The RCPT value decrease percentage is reducing when the binder content is increasing. When the binder content 350kg/m^3, the RCPT value is 21% and when the binder content is 400kg/m^3, the RCPT value is 16.9% and when the 450kg/m^3, the RCPT value is 12%.
3. For same binder content and with w/b ratios 0.4, 0.45 and 0.5, the RCPT value increases with the increasing of water binder ratio up to 30% of fly ash replacement. In between 30 to 60% of fly ash the variation is negligible.
4. For same w/b ratio and with varying binder content (350kg/m^3, 400kg/m^3 and 450kg/m^3) the RCPT value decreases with the increase of binder content up to 30% of fly ash replacement and in between 30 to 60% of fly ash replacement, RCPT value increases with increase of binder contents but still it is lesser than the concrete without fly ash.

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