Permeation Properties of Self – Compacting Concrete using High Volume Fly Ash

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Abstract

The use of self-compacting concrete (SCC) is highly recommended in the places where thin structural members with congested reinforcements are used. Permeation properties such as permeability, absorption, diffusivity etc., need to be studied to quantify the durability characteristics of SCC. This paper presents the results of experimental investigation on permeation properties of different grades of SCC containing high volume fly ash and the test results have been compared with conventionally vibrated concrete (CVC). Experiments were carried out on different grades (30MPa-60MPa) of SCC, designed based on a rational mix design method with high volume fly ash. The results on the permeation properties show that permeability and adsorption characteristics of all grades of SCC are lower than the CVC of same grades. The chloride diffusivity was found to be much dependent on the fly ash content. SCC with more fly ash content shows lesser diffusivity was found to be much dependent on the fly ash content. SCC with more fly ash content shows lesser diffusivity compared to other grades. It can be concluded that all grades of SCC produce better durability characteristics compared to CVC of same grades.

Keywords — *Self –Compacting Concrete, durability, permeability, absorption, sorptivity and diffusivity.*

I. INTRODUCTION

Self – compacting concrete (SCC) with excellent deformability and segregation resistance was first developed in Japan in 1986. It is a special kind of concrete, which flows through and fills the formwork, passes through the restricted spacing of congested reinforcement without segregation and compacts by itself without any need of external vibration. Mix design for SCC is normally done by trial and error method based on the EFNARC guidelines and specifications recommended by Okamura [1]. SCC mixes are produced using High Range water Reducing admixtures (HRWRA) and use large quantity of powder materials with effective use of viscosity – modifying admixtures (VMA). Okamura, et.al [2] has proposed a mix design method and test methods to study the workability characteristics of SCC. It is also suggested that the super plasticizer is necessary for producing a highly fluid concrete mix, while the powder materials and viscosity agents are required to maintain stability of the mix, hence reducing bleeding and segregation [3]. Furthermore, there are restrictions with regard to maximum size of coarse aggregates to reduce the risk of blocking in the place of highly congested reinforcements and narrow openings in the formwork. EFNARC [4] has given the specifications and guidelines for mix design of SCC. Annie. P et.al [5] has made the experimental investigations on the durability characteristics and the results show that self-compacting concrete has better durability characteristics than the conventionally vibrated concrete relating to absorption, permeability and chloride diffusivity. Wenzhong Zhu and Peter J.M. Bartos [6] did the experimental work on the permeation properties on SCC and concluded that SCC has lower values of coefficient of permeability and sorptivity of water absorption comparing to the traditionally vibrated concrete and also the SCC mixes with no additional powder content is having higher permeability, sorptivity and chloride diffusivity. Collepardi, M and Bertil [7,8] have studied the permeation properties of SCC and the results indicate a relativity lower chloride penetration in SCC. Barrita et.al [9] has studied the water absorption properties of SCC and has reported that it has higher penetration resistance. The main objective of this study is to systematically assess the durability characteristics of SCC produced with high volume fly ash. Here water absorption, water permeability and chloride diffusivity of different types of SCC mixes are studied and compared with the CVC of same grade.

II. EXPERIMENTAL INVESTIGATION

A. Materials Used:

1) Cement:

Ordinary Portland cement (53 Grade) with specific gravity of 3.14 confirms to IS 12269 : 1987 (ASTM C 150 – 85A).

2) Fine Aggregate:

Locally available river sand of specific gravity 2.64, fineness modulus of 2.17, bulk density of 1320 kg/m^3 which confirms to Zone II as per IS : 2386 (Part I).

3) Coarse Aggregate:

Crushed granite coarse aggregate of 12mm down size with specific gravity of 2.79 and bulk density of 1480 kg/m^3 confirms to ASTM C 33 – 86.

4) Water:

Potable water confirms to ASTM D 1129, for mixing the concrete and curing of the specimens.

5) Fly Ash:

Class F fly ash obtained from Ennore Thermal Power Plant in Chennai with a specific gravity of 2.10 and fineness of 428 M2/kg determined as per IS 1727 : 1967 confirms to (ASTM C 618).

6) High Range Water Reducing Admixtures (HRWRA):

Polycarboxylicether (PCE) based superplasticiser confirms to ASTM C 494 – 92 Type A and Type F in aqueous form to enhance workability and water retention.

7) Viscosity Modifying Admixture (VMA):

A Polysaccharide based VMA, to enhance segregation resistance, to improve the viscosity and to modify cohesiveness of the mix.

B. Mix Design

In the present investigation SCC mixes were produced based on a rational mix method for high volume fly ash as presented by Binu. S et.al [10] for different grades of SCC (30MPa- 60MPa). The mix proportions are given in the table I. CVC mixes are produced with a normal workability (Slump of 30 – 50mm) based on the ACI committee method [11] and were verified by the trial mixes.

Table I : Details of Mix Designs of SCC and CVC

Material	CVC- proportions (kg/m^3)				SCC- proportions (kg/m^3)			
	C30	**C40**	**C50**	**C60**	**S30**	**S40**	**S50**	**S60**
Cement	385	416	445	476	250	333	417	500
Fly ash	-	-	-	-	275	215	153	101
Natural Sand	632	620	586	545		842	835	828
Coarse Aggregate	1176	1158	1142	1128		772	766	759
Water	200	200	200	200	178	180	182	186
Superplasticiser (% of Binder)	-	-	-	-	0.4	0.4	0.6	0.7
VMA (% of Binder)	-	-	-	-	0.1	0.1	0.1	0.1
W/P Ratio	0.52	0.48	0.45	0.42	0.34	0.33	0.32	0.31

C. Fresh Concrete Properties

The fresh concrete properties of different grades of SCC mixes are studied by conducting the following tests such as Slump flow test, V-Funnel test, L-Box test and U- box test. Slump flow test is to measure the flow ability and the respective requisites are a final spread of 60 – 75 cm in flow time of 1083s. Additionally, time taken for slump flow spread to reach 50 cm should be 582s. L-box test is to measure the passing ability where the specified time for flow up to 20cm is 180.5s, 40cm is 2.580.5s and the ratio between the heights of 20 cm and 40 cm should be > 0.8. The gap between the rebar is set here at three times the size of aggregate. U-box test is used to assess the self-compatibility and it indicates the resistance of the mixes to flow around obstruction. It also indicates the tendency of the coarse aggregate particles to stay back or settle down while flowing through closely spaced reinforcements. The height raised on the other side of the u-tube should be more than 30cm. V-funnel test is to determine viscosity of the mortar phase. It's used in adjusting the powder content, water content and admixture dosage. The Flow time may be from 8 to 12 Seconds. The setup and results for all the tests is shown in the Fig.1 and table II.

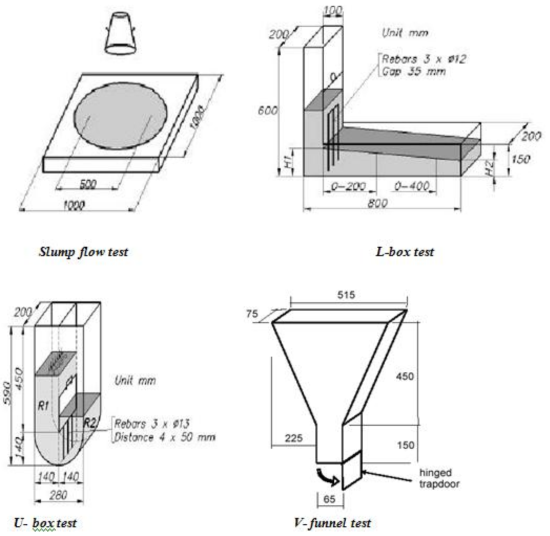

Fig. 1: Workability Test Apparatus

Table II : Workability Test Results

Grade	W/p	SP/b	Slump Flow	T_{50}cm Slump flow	V-Funnel flow T_f	V-Funnel flow T_{min}	L-Box T_{20}, T_{40}	L-Box h_1/h_2
	ratio	ratio	mm	s	s	s	s	ratio
S30	0.34	0.4	655	1.5	3	5	1, 1.5	0.86
S40	0.33	0.4	650	2.0	4	6	1.5, 2	0.87
S50	0.32	0.6	640	2.0	3	6	1, 1.5	0.85
S60	0.31	0.7	645	2.5	3	5	1, 1.5	0.85

D. Permeation Properties

Standard cubes and cylinder specimens were produced. The specimens for the SCC mixes were cast by pouring into the moulds without vibration while the CVC mixes were compacted on a vibrating table. The specimens were demoulded after 24th and the water cured. Further processing and preconditioning of specimens for testing of permeability properties were started at the age of 28 days. From the cylinder sample, a 100mm diameter core was taken and a 15mm to 20mm thick sections from both ends were cut off and discarded. The remaining core was then sliced into approximately 50mm thick disc specimens to be used for testing the diffusivity. Cube specimens are kept oven dry for 24 hours to carry over the water absorption and the permeability tests. Permeation properties of the concrete are usually classified into three main mechanisms, namely, diffusion, absorption and permeability.

1) Water Absorption Test:

Water absorption test was carried out as per ASTM C 642 – 97 [12]. Standard cubes were tested after28 days curing. The specimens were kept in side an oven for not less than 24 hours at a temperature of 100 to 110°C. The specimens were removed from the oven and allowed to cool in dry air to room temperature of 25oC. The dry weight (A) of the specimens was taken. Then the specimens were immersed in water and the weights were taken (B) at different time intervals. Specimens were weighed at a time internals of 30 minutes for the first 2.5 hour, after that every 1 hour up to 4 hour, then after, 24 hours, 48 hours, 72 hours, and tabulated. The water absorption and sorptivity were calculated as follows,

$$\text{Water Absorption } (\%) = \{(B-A)/A\} \times 100$$

$$\text{Sorptivity } (S) = (q/a) / t^{0.5}$$

Where

- A - Mass of over – dried sample in air (g)
- B - mass of surface dry sample in air after immersion (g).
- q - Water penetrated per unit surface area of exposure (m^3)
- a - Surface area (m^2)
- t - time (s)

2) Water Permeability Test:

Water Permeability test was carried out on standard cubs after 28 days of curing using German permeability apparatus. This apparatus was fixed on top surface of 150mm cubes. Water was filled in to the compression chamber and the pressure inside of the compression chamber was fixed at 5 bars. All air locks were removed. Due to water infiltration to pressure tended to reduce. A constant head was maintained by the inward movement of screw that accounts for the deplete volume of water. A micrometer attached to the screw gives the measure of infiltration. The readings of micrometer were noted at every two minutes up to 30 minutes. From this, value the permeability at different time intervals was calculated by using the formula,

$$\text{Water permeability in (m/s)}, P = (a \, \pi \, L \, r^2 / \pi \, R^2 \, t \, h.)$$

Where

- r = Radius of movable shaft of micro mater in m.
- a = Distance moved by the shaft to maintain constant pressure.
- R = Radios (m) of the compression chamber
- t = Time (s) during which the pressure is help con inside the compression chamber.
- L= Depth of penetration (m)
- h = Pressure head (m)

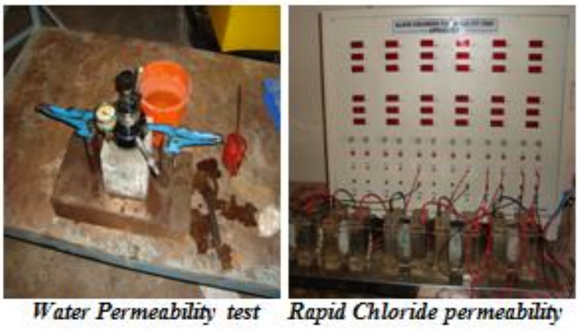

Fig. 2: Permeability Test Apparatus

3) Chloride Diffusivity Test:

This test was done as per ASTM C1202 - 97 [13]. First 100 diameter x 300mm height of cylinder was curing. This disc was kept in water up to testing. The specimens were removed from water and it was mound with applied voltage cell. The cathode cell was filled with 3% NaCl solution and anode cell was filled with 0.3N NaOH solution. This was connected to the 60 VDC Power supply. The current passed in the specimen was recorded using voltmeter for the time intervals at one hour up to six hours. Using these results the total ion charge through concrete specimen was calculated using the formula

$$Q = 900\,(I_0+2I_1+2I_2\text{----------------}+2I_{n-1}+ I_n).$$

Where

- Q = charge passed (coulombs).
- I_0 = current (amperes) immediately after voltage is applied
- I_t = current (amperes) at t hours after voltage is applied.

III.RESULTS AND DISCUSSIONS

The results of the water absorption test and the sorptivity values are given in the Table III. The result indicates that the SCC of higher grade of 50Moa and 60MPa shows lower percentage of water absorption than the mixes of 30Mpa and 40Moa, which contains high volume of fly ash at 28 days curing period. This may be due to the lack of hardening of fly ash based concrete during the early ages. Due to the presence of high volume fly ash, hardening and related properties are attained at a later period of curing (56 days, 90 days etc.) compared to conventional concrete. But, all the SCC mixes have shown low percentage of water absorption and sorptivity compared to the CVC mixes of same grade.

The results on the water permeability also show that SCC mixes are highly impermeable compared to the same grades of CVC mixes. It is observed that as the grade of concrete increases permeability reduces for both SCC and CVC mixes.

Table III: Results of Absorption, Permeability and Chloride Diffusely

Mix	Water absorption (%)	Sorptivity (10^{-6} m/s)	Water permeability (10-12 m/s)	RCPT (Coulombs)
C30	3.605	4.936	9.885	3120.5
C40	3.112	3.825	9.075	2915.7
C50	2.945	3.417	8.627	2567.8
C60	2.605	2.845	7.535	2385.1
S30	2.308	3.536	7.789	846.9
S40	2.106	2.750	6.780	980.1
S50	1.847	2.357	5.240	1233.3
S60	1.705	1.964	4.617	1360.2

The results of chloride migration value in coulombs obtained from the Rapid chloride Permeability Test (RCPT) are given in the Table III. Calories migration test results clearly indicate that the chloride diffusivity was highly inflexed by the high volume fly ash used in SCC. The grade of SCC with fly ash continues 52% of total powder content has very high impermeability than the other SCC mixers from the Table IV given by ASTM [13], SCC mixes of 30MPa and 40MPa are categorizer be ‘very low’ permeable and the mixes 50MPa are categorized to be ‘Low’ permeable concretes. SCC mixes are comparatively having very low chloride diffusivity than the CVC mixes.

Table IV: Range of Chloride Permeability as Per ASTM C 1202-94

Charged passed (coulombs)	Chloride permeability
<100	Negligible
>4000	High
2000 to 4000	Moderate
1000 to 2000	Low
100 to 1000	Very Low

IV. CONCLUSIONS AND SUGGESTIONS

SCC mixes show significantly lesser values of water permeability, percentage water absorption and sorptivity compared to the CVC mixes of the same grade.

The chloride diffusivity is found to be highly influenced by the amount of fly ash used in the concrete. SCC mix with high volume fly ash shows very low chloride diffusion than other mixes. The result also indicates that all the SCC mixes have lower chloride diffusivity compared to CVC mixes of same grade.

In general from the studies on the permeation properties on different SCC mixes shows that the durability characteristics of SCC is better than conventional concrete.

Permeation properties need to be studied a later periods of curing such as 56 days, 90 days etc. to study the hardening properties of high volume fly ash concrete.

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