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# DURABILITY CHARACTERISTICS OF SELF-COMPACTING CONCRETE CONTAINING LOW CALCIUM FLY ASH

Binu Sukumar[1], Joyson Silva P[2],

[1]*Professor&Head, Department of Civil Engineering, R.M.K Engineering College*
[2]*Assistant Professor, Department of Civil Engineering, R.M.K Engineering College*

**Abstract** - *Self-compacting concrete (SCC) would be an ideal choice for thin structural members with congested reinforcement as they pass freely and fill the formwork completely without segregation. Four SCC mixes with strengths of 30 MPa, 40MPa, 50MPa and 60MPa were cast using a rational mix design procedure evolved for SCC mixes using low calcium fly ash. The cement content in the mixes varied from 250 Kg/m$^3$ to 500kg/m$^3$ while the percentage of fly ash in the mixes varied from 52% to 18% of the binder content. A carboxyl Ted ether based superplasticiser in dosages of 0.4% to 0.7% of the binder content was helpful in enhancing the deformability of the mixes. A commercially available Viscosity Enhancing Agent (VEA) with a dosage of 0.1% of binder content was useful in enhancing the thixotropy of the mixes. The durability related properties of these mixes such as water permeability, percentage saturated water absorption, rapid chloride permeability test (RCPT), sorptivity and shrinkage were evaluated after 28 days of water curing and presented in the paper. It was observed that high strength SCC showed lower percentage of water absorption and coefficient of water permeability as compared to low strength SCC. However, based on the RCPT values, SCC having strengths up to 40 MPa could be categorized as 'very low' permeability and above as 'low' permeability concrete indicating the high degree of chloride impermeability of low strength mixes. Hence, low strength SCC could also be proportioned to be highly resistant to chloride diffusion. The investigations clearly demonstrated that SCC mixes could be considered as highly durable concrete*.

***Keywords***- *Self Compacting Concrete, Conventionally Vibrated Concrete, Mix design, Viscosity Enhancing Agent, Water absorption, Rapid chloride permeability test (RCPT), Sorptivity, Shrinkage, Permeability and Durability of concrete.*

## I. INTRODUCTION

Self – compacting concrete (SCC) having excellent deformability and segregation resistance was first developed in Japan in 1986 [1,2]. SCC readily flows and fills the formwork, passing through congested reinforcement with out segregation and compacting by itself without any need for external vibration. High Range Water reducing admixtures (HRWRA), large quantities of powdery materials and viscosity – enhancing admixtures (VEA) form part of the ingredients. HRWRAs are necessary for producing a highly fluid concrete mix, while the powdery materials and viscosity enhancing agent are required to maintain stability of the mix, thus eliminating bleeding and segregation [3]. Lower content of coarse aggregates prevents the risk of blocking in areas of highly congested reinforcement and narrow openings in the formwork.

SCC is normally designed based on guildelines recommended by Okamura or EFNARC specifications [4] which may require a number of trials. Hence, a rational mix design procedure to achieve strengths ranging from 30 MPa, to 60 MPa using high volumes of low calcium fly ash was evoled. SCC mixes having strengths of 30 MPa, 40 MPa, and 60 MPa at 28 days were cast and evaluated for the durability characteristics. Earlier researchers have demonstrated the enhanced durability characteristics of SCC. Annie. J et al [5] compared the durability related characteristics of SCC and Conventionally Vibrated Concrete (CVC) mixes of similar strengths and observed that self-compacting concrete has better durability characteristics relating to water absorption,permeability and cloride diffusivity.Wenzhong Zhu and Peter.J.M. Bartos [6] examined the permeation properties on SCC and concluded that SCC has lower values of coefficient of permeability and sorptivity compared to the traditionally Vibrated Concrete. They also noted that SCC mixes with VEA have higher permeabilty, sorptivity and chloride diffusivity compared to SCC mixes with higher powdery materials. Collepardi.M and Bertil [7,8] studied the permeation properties of SCC and the results indicate a relatively lower chloride penetration in SCC. Barrita et. al [9] studied the water absorption properties of SCC and found these concrete had higher water penetration resistance.

In the present experimental the durability related characteristics of four SCC mixes having 28 day, strengths of 30 MPa, 40MPa, 50MPa and 60MPa are assessed. The results of water absorption, water permeability, chloride diffusivity, sorptivity and the drying shrinkage of these mixes are presented in this paper.

## II. EXPERIMENTAL INVESTIGATION

### A. Materials Used

**Cement**

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

**Fine Aggregate**

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

**Coarse Aggregate**

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

**Water**

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

**Fly Ash**

Class F fly ash obtained from Ennore Thermal Power Plant near Chennai with a specific gravity of 2.10, fineness of 428 $m^2$/kg determined as per IS 1727:1967 conforms to (ASTM C 618).

**High Range Water Reducing Admixtures (HRWRA)**

Polycarboxylic ether (PCE) based super-plasticizer conforms to ASTM C 494 – 92 Type A and Type F in aqueous from to enhance workability and water retention.

**Viscosity Enhancing Admixture (VEA)**

A polysaccharide based VEA, 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 proportioned based on a rational mix design method for SCC containing fly ash as developed by Binu. S et.al [10]. The mix proportions arrived for the four mixes S30, S40, S50 and S60 are given in Table 1.

**Table 1 Details of Self Compacting Concrete Mixes**

| Mix proportions (kg/$m^3$) | Mix ID | | | |
|---|---|---|---|---|
| | S30 | S40 | S50 | S60 |
| Cement | 250 | 333 | 417 | 500 |
| Fly Ash | 275 | 215 | 153 | 101 |
| Natural Sand | 842 | 835 | 828 | 820 |
| Coarse aggregate | 772 | 766 | 759 | 753 |
| Water | 178 | 180 | 182 | 186 |
| Superplasticiser (% of binder*) | 0.4 | 0.4 | 0.6 | 0.7 |
| VEA (% of binder*) | 0.1 | 0.1 | 0.1 | 0.1 |
| W/P ratio | 0.34 | 0.33 | 0.32 | 0.31 |

* Binder = (Cement + Fly ash)

**Detail of the Tests**: Durability related tests such as (1) Saturated Water Absorption (2) German Water Permeability (3) Rapid chloride Permeability test and (4) Drying Shrinkage were carried out on the four SCC mixes (S30, S40, S50 and S60). The details of the specimens cast for the various tests and the test methods are described below.

**Preparation of Test Specimens:** The ingredients were weighted and a pan mixer of 30 liters capacity was used for mixing the ingredients thoroughly. SCC was poured into the moulds without vibration. Standard cubes of sizes 150 mm x 150 mm x 150 mm and 100 mm x 100 mm x 100 mm and cylinders of size 100 mm diameter x 200 mm height were cast. The specimens were demoulded after 24 h and cured in water for 28 days. Cylindrical discs of 50 mm height were cut from the cylindrical specimens of 100 mm diameter and 200 mm height for conducting the rapid chloride permeability test.

**C. Durability Related Test Methods**

**Water Absorption Test**

Water absorption test was carried out as per ASTM C 642-97[11]. The test was done on cube specimens of 100' mm size after 287 days of water curing. The specimens were kept in an oven at a temperature of 100 to 1100C until constant weights were obtained (greater than 24 hours). The specimens were next removed from the oven and allowed to cool in ambient room temperature. The oven 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 weighted at time internals of 30 minutes for the first 2.5 hours, after that every 1 hour up to next 4 hours, then after, 24 hours, 48 hours and at the end of 72 hours. The percentage water absorption and sorptivity were calculated as follows, Water absorption (%) = {(B-A)/A} x 100

Sorptivity = (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 = Volume of water penetrated (m3).
a = Surface area ($m^2$).
t = Time (s)

**Water Permeability test**

Water permeability test was carried out on 150 mm cubes after 28 days of water curing using German permeability apparatus. The apparatus was fixed on top surface of the cube as shown in Figure-1. Water was filled in to the compression chamber and the operating pressure inside the compression chamber was fixed at 5 kg/$cm^2$. Care was taken to ensure the chamber free of any air bubbles. As the water infiltrated into the specimen the pressure reduced in the chamber. The pressure was maintained constant (5 kg/$cm^2$) by the inward movement of screw that accounted for the depleted volume of water. A micrometer attached to the screw gave the measure of infiltration. The readings of the micrometer were noted at every two minutes up to 30 minutes. From this value, the permeability at different time intervals were calculated by using the formula,

Water permeability m/s = P = (a π L r2 / π R2 t h)

Where,

r = Radius of movable shaft of micrometer (m)
a = Distance moved by the shaft to maintain constant pressure
R = Radius (m) of the compression chamber
t = Time (s) during which the pressure is held constant inside the Compression chamber
L = Depth of penetration (m)
H = Pressure head (m)

Figure-1 German Water Permeability Test

**Rapid Chloride Permeability Test**

This test was done as per ASTM C 1202 – 97 [12]. Cylindrical discs of 50 mm thick were cut from the cylindrical specimens of 100 mm diameter and 200 mm height for conducting the rapid chloride permeability test after 28 days of water curing. The diffusion apparatus consists of two cells with copper electrodes. The cathode cell was filled with 3% NaC1 solution and anode cell was filled with 0.3N NaOH solution. The disc shaped specimen was mounted centrally in between these cells. The cells were connected to the 60 V DC power supply Figure-2. Current passed from cathode to anode through the specimens. This was recorded at every one hour for a period of six hours. Using these values the total ion Charges passed through concrete specimen was calculated using the formula

**Q = 900 (I 0 + 2 I1 + 2 I2 + ----------- + 2 In-1 + In)**

Where,

Q = Charges passed (coulombs).

 

$I_0$ = current (amperes) immediately after voltage is applied.
$I_t$ = current (amperes) at t hours after voltage is applied.

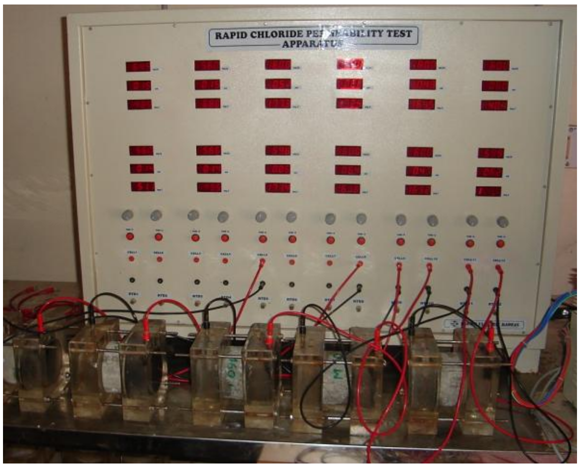


Figure-2 Rapid Chloride Permeability Test

Table 2 Chloride ion permeability of concrete based on charges passed (ASTM C 1202 – 94)

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

Table 3 Water absorption, Water permeability and Rapid chloride permeability of SCC mixes (28 days)

| Mix ID | Water absorption (%) | Sorptivity ($10^{-6}$ m/s$^{0.5}$) | Water permeability $10^{-12}$ m/s) | RCPT (Coulombs) |
|---|---|---|---|---|
| S30 | 2.308 | 3.536 | 7.786 | 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 |

**Drying Shrinkage test**

This test was done as per ASTM C 596 – 89[13]. Prism shaped specimens (Figure- 3) were cast in steel moulds of size 25 x 25 x 250 mm. After 24 hours of moist curing, the specimens cured in water for 48 hours. At age of 72 hours, the specimens were stored in microprocessor controlled environmental chamber Figure- 4. The length comparator readings were taken at ages of 7, 14, 21, 28 days. Linear shrinkage of each specimen was calculated at each age by subtracting the initial comparator reading, taken immediately after the removal from water storage, from the comparator reading taken at each age of air drying and expressed as millionths effective gauge length. The drying shrinkage was calculated using the formula,

$$L = \{(Lx - Li) / G\}$$

Where,

| | | |
|---|---|---|
| L | = | change in length at x age (percentage). |
| Lx | = | comparator reading of specimen at x age (mm). |
| Li | = | initial comparator reading of specimen (mm). |
| G | = | nominal gauge length (mm). |

 

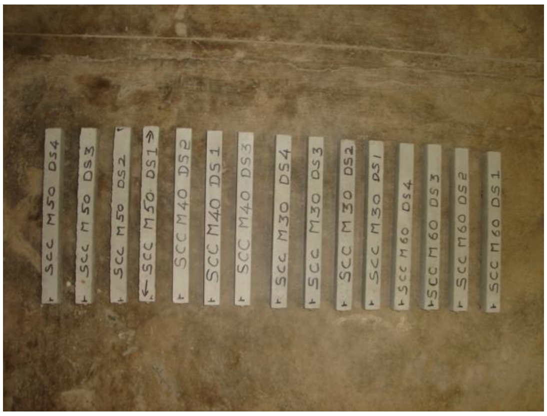

Figure- 3 Drying shrinkage test specimens

Figure-4 Drying shrinkage test setup

Table 4 Drying Shrinkage of SCC Mixes

| Mix ID | Drying Shrinkage (micro strains) | | | |
|---|---|---|---|---|
| | 7 days | 14 days | 21 days | 28 days |
| S30 | 146 | 131 | 118 | 110 |
| S40 | 370 | 365 | 334 | 258 |
| S50 | 518 | 451 | 400 | 336 |
| S60 | 594 | 520 | 432 | 368 |

## III. RESULTS AND DISCUSSIONS

The results of the water absorption test and the sorptivity values for all the mixes are given in the Table 3. The percentage water absorption ranged from 1.7% to 2.3% indicating the low water absorption of all the mixes. However, SCC mixes of strengths in the range of 50 MPa to 60 MPa showed lower percentage of water absorption compared to mixes of 30 MPa and 40 MPa strengths. The higher values of water absorption of lower strength concrete may be due to the higher contents of fly ash in the mixes. The water absorption values are expected to reduce at ages later than 90 days due to the pozzolonic reactivity of fly ashes. Similar results were also observed in the water permeability tests. The water permeability of high strength SCC was lower than low strength SCC.

The results of chloride permeability values in coulombs obtained from the Rapid Chloride permeability Test (RCPT) are tabulated in Table 3. The ASTM C 1202 classification for the chloride permeability of concrete based on the charges passed thorough them is given in Table 2. The test results clearly indicate that the charges passed through the specimens were highly influenced by the fly ash content in the mixes. The S30 mix with a fly ash content of 52% of total binder content had very low chloride permeability compared to the other SCC mixes. Based on the test results, SCC mixes with strengths of 30 MPa and 40 MPa can be categorized as ‘very low’ permeability concrete and mixes with strengths of 50 MPa and 60 MPa can be categorized to be ‘low’’’ chloride permeability concrete.

The drying shrinkage at the age of 28 days for mixes S30, S40, S50, and S60 were 594, 520, 432 and 368 micro strains respectively and are tabulated in table 4.

## IV. CONCLUDING REMARKS

- SCC mixes of strengths varying from 30MPa to 60MPa shows significantly lesser values of water permeability, water absorption and sorptivity.

 

- The chloride permeability is found to be highly influenced by the amount of fly ash content in the mixes. SCC mixes with higher fly ash contents show very low chloride permeability.
- The drying shrinking strains of all the mixes were low.
- SCC mixes can be considered as highly durable concrete. It is also expected that at later ages the durability properties of SCC containing high contents of fly ash would have lower water absorption. Hence permeation characteristics may be studied at later periods such as 56 days, 90 days etc.

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