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# Studies on Effect of Mineral Admixtures on Durability of Self Compacting Concrete

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**ABSTRACT**

*This paper presents durability study on self compacting concrete (SCC) with various partial replacements of fly ash, silica fume and combination of both fly ash and silica fume. The slump, V-funnel and L-Box test are carried out on the fresh SCC and in harden concrete compressive strength and split tensile strength values are determined. Attempts have been made to investigate the suitability of various replacements and also to study the durability properties such acid resistance, sulphate attack, alkaline attack, sorptivity, chloride permeability of SCC mixes.*

**Key words:** Self compacting concrete, durability, deterioration, viscosity modifying agent, workability

## INTRODUCTION

Self-compacting concrete (SCC) is considered as a concrete which can be placed and compacted under its self weight with little or no vibration effort, and which is at the same time cohesive enough to be handled without segregation or bleeding of fresh concrete. SCC mixes usually contain superplasticizer, high content of fines and/or viscosity modifying additive (VMA). Whilst the use of superplasticizer maintains the fluidity, the fine content provides stability of the mix resulting in resistance against bleeding and segregation.

However, the high dosage of super-plasticizer used for reduction of the liquid limit and for better workability, the high powder content as 'lubricant' for the coarse aggregates ,as well as the use of viscosity-agents to increase the viscosity of the concrete have to be taken into account. Super plasticizer enhances deformability and with the reduction of water/powder segregation resistance is increased. High deformability and high segregation resistance is obtained by limiting the amount of coarse aggregate. These two properties of mortar and concrete in turn lead to self compactability limitation of coarse aggregate content.

## MATERIALS USED IN THIS EXPERIMENT

### Cement

In this experimental study, Ordinary Portland Cement conforming to IS: 8112-1989 was used. The physical and mechanical properties of the cement used are shown in Table-1.

### Fly ash (Class –F type)

The flow ability of self compacting concrete depends on the powder and paste content. Hence, in order to increase the flow ability, mineral admixtures such as fly ash has been used. A class 'F' fly ash obtained from Ennore Thermal Power Plant (Chennai, Tamil Nadu) was used. Table -2 gives the physical properties of the fly ash.

### Silica Fume

Silica fume is a waste by-product of the production of silicon and silicon alloys. Silica fume is available in different forms, of which the most commonly used now is in a densified form. In developed countries it is already available readily blended with cement. The details of silica fume used in this experiment are in the Table-3

### Aggregates

Locally available natural sand with 4.75 mm maximum size was used as fine aggregate, having specific gravity, fineness modulus and unit weight as given in Table-4 and crushed stone with 12mm maximum size having specific gravity, fineness modulus and unit weight as given in Table-4 was used as coarse aggregate. Table-4 gives the physical properties of the coarse and fine aggregates.

### Super plasticizer (SP)

The admixture used was a superplasticizer based on viscosity modified polycarboxylates, which was used to provide necessary workability. A new generation based Polycarboxylic ether (PCE) was used, which is known as PCE (Viscosity Modified). Table-5 gives the Properties of PCE.

### Water

Ordinary tap water is used.

**Table-1 Properties of Cement**

| Physical property | Results |
|---|---|
| Fineness (retained on 90-µm sieve) | 8% |
| Normal Consistency | 28% |
| Vicat initial setting time (minutes) | 75 |
| Vicat final setting time (minutes) | 215 |
| Specific gravity | 3.15 |
| Compressive strength at 7-days | 20.6 MPa |
| Compressive strength at 28-days | MPa |

**Table-2 Properties of Fly Ash**

| Physical Properties | Test Results |
|---|---|
| Colour | Grey (Blackish) |
| Specific Gravity | 2.12 |

**Table-3 Details of Silica Fume**

| Code | 920-D |
|---|---|
| Type | Densified (Non-Combustible) |
| Main content | Amorphous $SiO_2$ |

**Table-4 Physical Properties of Coarse and Fine Aggregates**

| Property | Fine Aggregate | Coarse Aggregate |
|---|---|---|
| Specific Gravity | 2.56 | 2.7 |
| Fineness Modulus | 3.1 | 7.69 |
| Surface Texture | Smooth | -- |
| Particle Shape | Rounded | Angular |
| Crushing Value | --- | 17.40 |
| Impact Value | --- | 12.50 |

**Table-5 Properties of PCE**

| Name | CONXL-PCE 8860 (Viscosity Modified) |
|---|---|
| Color | Dark Amber Color |
| Solid Content | 40% |
| *Ph* | 8.0 |
| Specific Gravity | 1.14 |

## SCC MIX DESIGN

Several methods exist for the mix design of SCC. The general purpose mix design method was first developed by Okamura and Ozawa (1995). In this study, the key proportions for the mixes are done by volume. The detailed steps for mix design are described as follows:

- Assume air content as 2% (20 litres) of concrete volume.
- Calculate the coarse aggregate content by volume (28 – 35%) of mix volume.
- Adopt fine aggregate volume of 40 to 50% of the mortar volume.
- Replace cement with Class F type fly ash, silica fume and the combination of both by weight of cementitious material.
- Optimize the dosages of super plasticizer (viscosity modified)
- Perform SCC tests.

**Table-6 Mix Design Proportions SCC for Different Combination**

| | | | | W/B= 0.36 | | S.P %=0.9 | |
|---|---|---|---|---|---|---|---|
| Mix | Binder (kg/m³) | | | Fine Agg kg/m³ | Coarse Agg kg/m³ | Water kg/m³ | S.P kg/m³ |
| | Cement | Fly Ash | Silica | | | | |
| SCC | 536.00 | --- | --- | 836 | 771.84 | 192.26 | 4.824 |
| FA10 % | 472.00 | 52.45 | --- | 836 | 771.84 | 188.82 | 4.721 |
| FA20% | 410.80 | 102.70 | --- | 836 | 771.84 | 184.86 | 4.622 |
| FA30% | 351.75 | 150.75 | --- | 836 | 771.84 | 180.90 | 4.523 |
| SF5% | 506.35 | --- | 26.65 | 836 | 771.84 | 191.88 | 4.797 |
| SF10% | 477.00 | --- | 53.00 | 836 | 771.84 | 190.80 | 4.770 |
| SF15% | 447.95 | --- | 79.05 | 836 | 771.84 | 189.72 | 4.743 |
| SF20% | 418.80 | --- | 105.00 | 836 | 771.84 | 188.46 | 4.712 |
| SF5+FA30 | 324.68 | 149.85 | 25.00 | 836 | 771.84 | 179.82 | 4.500 |
| SF10+FA20 | 355.25 | 101.50 | 50.75 | 836 | 771.84 | 182.70 | 4.570 |
| SF15+FA10 | 378.00 | 50.40 | 75.60 | 836 | 771.84 | 181.44 | 4.536 |

### Mixing procedure for SCC

Mixing procedure for SCC is described as follows:

- Binder and aggregate are mixed for one minute.
- The 1st part (70%) of water was added and mixed for two minutes.
- SP along with the 2nd part (30%) of water was added and mixed for two minutes.
- The mix was stopped and kept rest for 2 minutes.
- The mix was remixed for one minute and discharged for SCC tests

## TESTING FRESH PROPERTIES OF SCC

### Slump Flow Test

Slump flow test apparatus is shown in Figure 1(a). Slump cone has 20 cm bottom diameter, 10 cm top diameter and 30 cm in height. In this test, the slump cone mould is placed exactly on the 20 cm diameter graduated circle marked on the glass plate, filled with concrete and lifted upwards. The subsequent diameter of the concrete spread is measured in two perpendicular directions and the average of the diameters is reported as the spread of the concrete. T50cm is the time measured from lifting the cone to the concrete reaching a diameter of 50cm. The measured T50cm indicates the deformation rate or viscosity of the concrete.

### V-Funnel Test

V-Funnel test apparatus is shown in Figure 1(b). In this test, trap door is closed at the bottom of V-Funnel and V-Funnel is completely filled with fresh concrete. V-Funnel time is the time measured from opening the trap door and complete emptying the funnel. Again, the V-Funnel is filled with concrete, kept for 5 minutes and trap door is opened. V-Funnel time is measured again and this indicates V-Funnel time at T5min.

### L-Box Test

L-Box test apparatus is shown in Figure 1(c). In this test, fresh concrete is filled in the vertical section of L-Box and the gate is lifted to let the concrete to flow into the horizontal section. The height of the concrete at the end of horizontal section represents h2 (mm) and at the vertical section represents h1 (mm). The ratio h2/h1 represents blocking ratio.

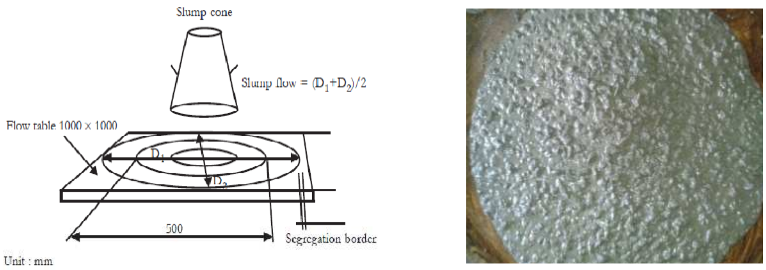


**Fig. 1(a) Slump flow& T50 sec Test**

**Fig. 1(b) V-Funnel Test**

**Fig. 1(c) L-Box Test**

**Table - 7 Result of Fresh Properties of SCC Mixes with Different Partial Replacement of Mineral Admixtures**

| S.No | Mix | Slump (mm) | T50 (sec) | V-Funnel (sec) | T5 min (sec) | L-Box ($h_2/h_1$) |
|---|---|---|---|---|---|---|
| 1 | SCC 0 | 675 | 4.4 | 12 | 13.5 | 0.9 |
| 2 | FA10% | 682 | 4.0 | 11.0 | 13.1 | 0.86 |
| 3 | FA20% | 692 | 3.6 | 10.8 | 12.8 | 0.84 |
| 4 | FA30% | 710 | 3.1 | 9.2 | 12.3 | 0.81 |
| 5 | SF5% | 670 | 4.6 | 10.2 | 13.0 | 0.9 |
| 6 | SF10% | 667 | 4.8 | 10.5 | 13.5 | 0.92 |
| 7 | SF15% | 660 | 4.9 | 10.7 | 13.8 | 0.96 |
| 8 | SF20% | 650 | 5.0 | 11.0 | 14.2 | 0.98 |
| 9 | SF5+FA30 | 692 | 3.4 | 8.2 | 11.9 | 0.83 |
| 10 | SF10+FA20 | 680 | 3.6 | 8.5 | 12.3 | 0.9 |
| 11 | SF15+FA10 | 675 | 3.8 | 9.0 | 12.8 | 0.92 |
| **#** | **EFNARC** | **650-800** | **2-5** | **6-12** | **6-15** | **0.8-1.0** |

## DURABILITY TEST METHODS

Durability studies were conducted at 28, 56 and 90days for various mixes to find out the resistance to acid attack, sulphate attack and saturated water absorption.

### Acid Resistance

Acid resistance was tested on 150 mm size cube specimens at the age of 28 days of curing. The cube specimens were weighed and immersed in water diluted with three percent by weight of Hydrochloric acid for 28 days. The specimens are arranged in a plastic tubs in such a way that clearance around and above the specimen is not less than 30mm. Then, the specimens were taken out from the acid water and the surfaces of the cubes were brushed with a soft nylon brush and rinsed with tap water. This process removes loose surface material from the specimen. Then, the weight and the compressive strength of were found out and the average percentage of loss of weight and compressive strength were calculated.

**Sulphate Attack**

The sulphate attack testing procedure was conducted by immersing concrete specimens of the size 150x150x150 mm over the specified initial curing in a water tank. Then, they were cured in 3% Sodium sulphate solution and 3% Magnesium Sulphate for 28 days. This type of testing represents an accelerated testing procedure, which indicates the performance of particular concrete mixes to sulphate attack on concrete. The degree of sulphate attack was evaluated by measuring the weight losses of the specimens at 28 days.

**Alkaline Test**

The sulphate attack testing procedure was conducted by immersing concrete specimens of the size150x150x150 mm over the specified initial curing in a water tank. Then, they were cured in 3% Sodium Hydroxide for 28. This type of testing represents an accelerated testing procedure, which indicates the performance of particular concrete mixes to sulphate attack on concrete. The degree of sulphate attack was evaluated by measuring the weight losses of the specimens at 28 days.


**Fig. 2 Alkaline, Acid and Sulphate Test**

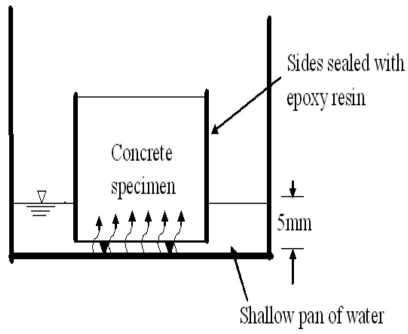


**Fig. 3 Sorptivity Test Arrangement**

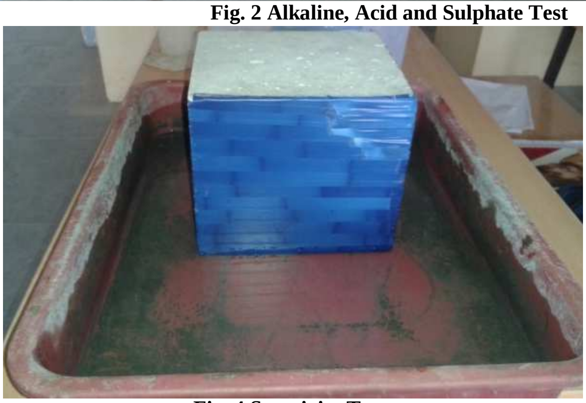

**Fig. 4 Sorptivity Test**

**Fig. 5 Chloride Penetration Test**

**Sorptivity Test**

Standard 150mm cube specimens were cast. On the following day of casting, the specimen were de-moulded and located in water curing condition for a period of 28 days. Water absorption tests were carried out to determine the Sorptivity coefficient of concrete specimens which were preconditioned in oven at105$^{o}$c for 24 hours to achieve a constant moisture level. Then, four sides of concrete specimens were sealed by electrical tape to avoid evaporative effect as well as to maintain uniaxial water flow during the test and opposite faces left open. Before locating the specimens on water, their initial weight was recorded. One face of specimen was in contact with water, while the water absorption at predefined intervals was noted by taking by weight. The specimen was submerged 5mm in water.

Procedure was repeated, consecutively at various time intervals 15min., 30min., 1hr, 2hr, 4hr, 6hr, 24hr, 48hr and 72hr until the last reading. Sorptivity coefficient can be calculated by the following expression.

$$S= (Q/A)/ (t)^{½} \quad (1)$$

Where, S=Sorptivity (cm/s$^{1/2}$), Q=vol. of water absorbed in cm$^3$, A=Surface area in contact with water in cm$^2$ & t=Time in Sec.

## Chloride Permeability Test

In chloride permeability test, concrete blocks were immersed in 3% NaCl solution after period of 28 days the specimens were removed from curing tank and their surfaces were cleaned with soft nylon brush to remove weak reaction products.

After a specified duration (28 days) specimen were removed from solution, split and the depth of chloride penetration was determined in one half of the specimen using a colorimetric technique in which silver nitrate solution was used as a colorimetric indicator. When silver nitrate solution was sprayed on a concrete containing chloride ions, a chemical reaction occurred. The chlorides bind with the silver to produce silver chloride, a whitish substance. In the absence of chlorides, the silver instead bonds with the hydroxides present in the concrete creating a brownish colour. A whitish colour at the border of specimen shows the depth of penetration.

# DURABILITY PROPERTIES OF SCC MIXES

## Acid Resistance

Weight and compressive strength value of the specimens were found out for the age of 28 days. The average percentage of weight loss and compressive strength were calculated for acid test as shown in Table-8 and Fig.6 & 7 shows the graph for the acid resistance. Based on the result, it shows that the acid resistance of SCC is high when compared to the conventional concrete. In SCC, the partial replacement of silica fume has higher acid resistance than the partial replacement of fly ash.

**Table-8 Acid Resistance Test Result**

| MIX | Initial wt. (kg) | Final wt. (kg) | % of Loss of wt. | Initial comp. str.(MPa) | Final comp. str.(MPa) | % of loss of comp.str. |
|---|---|---|---|---|---|---|
| CVC | 8.46 | 8.21 | 2.95 | 37.2 | 33.2 | 11.15 |
| SCC | 7.8 | 7.6 | 2.56 | 40 | 35.8 | 10.50 |
| FA10% | 7.86 | 7.69 | 2.16 | 43.2 | 39.31 | 9.26 |
| FA20% | 7.89 | 7.75 | 1.77 | 45.5 | 41.2 | 9.1 |
| FA30% | 7.9 | 7.77 | 1.64 | 42.6 | 38.866 | 8.80 |
| SF5% | 7.7 | 7.56 | 1.78 | 43.2 | 39.31 | 9.027 |
| SF10% | 7.76 | 7.63 | 1.67 | 46.3 | 42.19 | 8.87 |
| SF15% | 7.82 | 7.70 | 1.53 | 52.2 | 47.70 | 8.62 |
| SF20% | 7.83 | 7.72 | 1.41 | 36.8 | 33.65 | 8.55 |
| SF5%+FA30% | 7.8 | 7.68 | 1.53 | 34 | 31.20 | 8.23 |
| SF10%+FA20% | 7.84 | 7.71 | 1.65 | 44.5 | 40.95 | 7.97 |
| SF15%+FA10% | 7.86 | 7.72 | 1.70 | 48.2 | 44.50 | 7.67 |

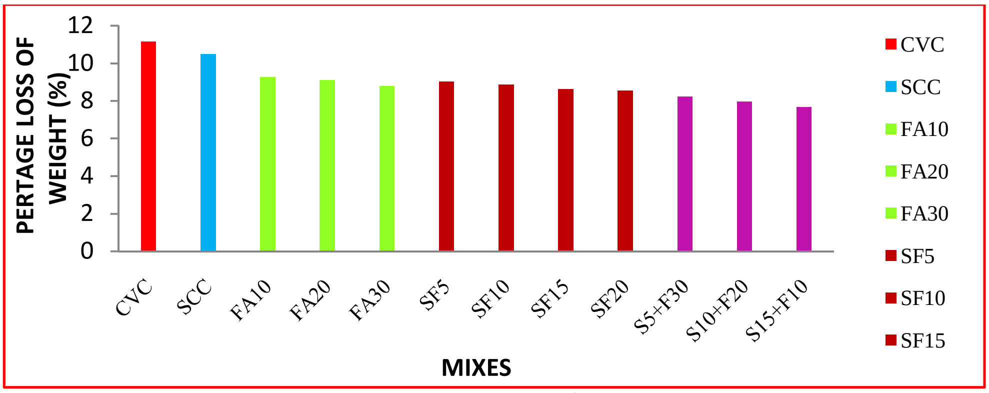


**Fig. 6 Acid Attack (Loss of Weight)**

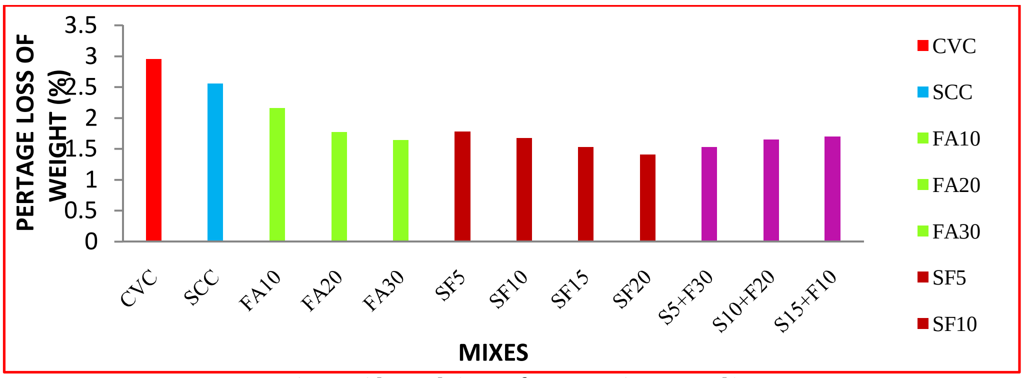


**Fig. 7 Acid Attack (Loss of Compressive Strength)**

### Sulphate Attack

The sulphate attack was evaluated by measuring the weight loss of the specimen at 28 days. The results for sulphate attack test are shown above. Based on the result, it shows that the sulphate resistance of SCC is high when compared to the conventional concrete. In SCC, the partial replacement of silica fume has higher sulphate resistance than the partial replacement of fly ash.

### Alkaline Attack

The alkaline attack was evaluated by measuring the weight loss of the specimen at 28 days. The results for alkaline attack test are shown in Table 10 and in Fig.9. Based on the result, it shows that the alkaline resistance of SCC is high when compared to the conventional concrete. In SCC, the partial replacement of silica fume has higher alkaline resistance than the partial replacement of fly ash.

**Table-9 Sulphate Attack Test Results**

| MIX | Initial wt. (kg) | Final wt. (kg) | % of loss of weight |
|---|---|---|---|
| CVC | 8.46 | 8.352 | 1.27 |
| SCC | 7.8 | 7.710 | 1.15 |
| FA10% | 7.86 | 7.772 | 1.12 |
| FA20% | 7.89 | 7.802 | 1.10 |
| FA30% | 7.9 | 7.823 | 0.97 |
| SF5% | 7.7 | 7.627 | 0.94 |
| SF10% | 7.76 | 7.688 | 0.92 |
| SF15% | 7.82 | 7.750 | 0.89 |
| SF20% | 7.83 | 7.762 | 0.86 |
| SF5%+FA30% | 7.8 | 7.732 | 0.87 |
| SF10%+FA20% | 7.84 | 7.772 | 0.86 |
| SF15%+FA10% | 7.86 | 7.793 | 0.84 |

**Table-10 Alkaline Attack Test Results**

| MIX | Initial wt. (kg) | Final wt. (kg) | % of loss of weight |
|---|---|---|---|
| CVC | 8.46 | 8.378 | 0.969 |
| SCC | 7.8 | 7.725 | 0.961 |
| FA10% | 7.86 | 7.786 | 0.941 |
| FA20% | 7.89 | 7.818 | 0.912 |
| FA30% | 7.9 | 7.828 | 0.911 |
| SF5% | 7.7 | 7.632 | 0.883 |
| SF10% | 7.76 | 7.692 | 0.876 |
| SF15% | 7.82 | 7.753 | 0.856 |
| SF20% | 7.83 | 7.765 | 0.830 |
| SF5%+FA30% | 7.8 | 7.732 | 0.846 |
| SF10%+FA20% | 7.84 | 7.774 | 0.841 |
| SF15%+FA10% | 7.86 | 7.210 | 0.826 |

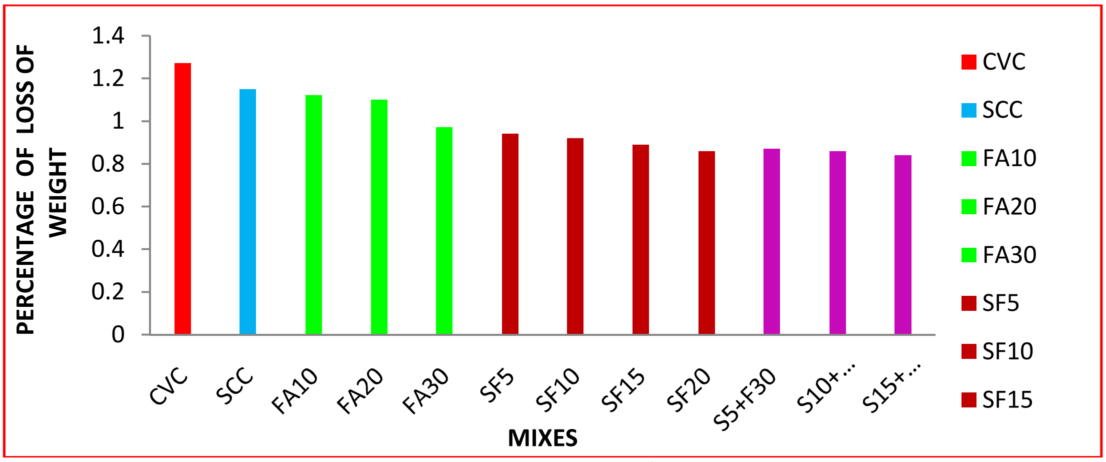


**Fig. 8 Sulphate Attack (Loss of Weight)**

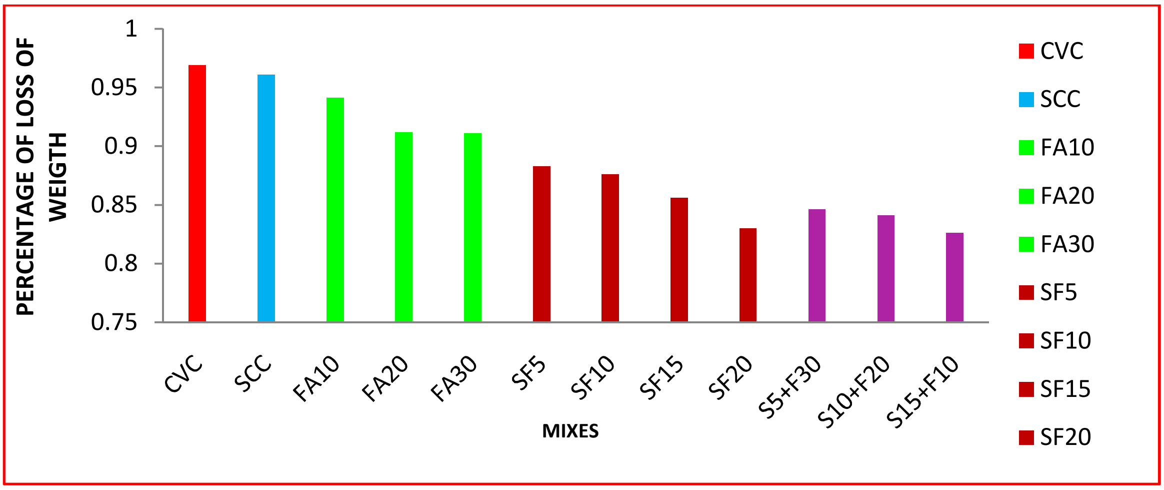


**Fig. 9Alkaline Attack (Loss of Weight)**

## Sorptivity

Sorptivity coefficient was determined by means of simple test allowing one face of concrete specimen in contact with water and the mass of water absorbed by capillary suction was measured at predefined intervals. The results of Sorptivity tests are given in Table-11 and Fig.10 shows graph. Based on the result, it shows that the Sorptivity of SCC is low when compared to the conventional concrete. In SCC, the partial replacement of silica fume has low Sorptivity than the partial replacement of fly ash.

## Chloride Permeability Test

It is evident that the pozzolanic admixture creates a more compact concrete. The chloride ion penetration decreases when the admixture added because they physically occupy pores in the cement paste by virtue of their particle size. Table-12 and Fig.11 shows the depth of penetration. . Based on the result, it shows that the depth of penetration of SCC is low when compared to the conventional concrete. In SCC, the partial replacement of silica fume has low depth of penetration than the partial replacement of fly ash.

**Table-11 Results of Sorptivity**

| Mix | Sorptivity (cm/s$^{1/2}$) |
|---|---|
| CVC | $3.0 \times 10^{-3}$ |
| SCC | $2.5 \times 10^{-3}$ |
| FA10% | $2.32 \times 10^{-3}$ |
| FA20% | $2.12 \times 10^{-3}$ |
| FA30% | $2.0 \times 10^{-3}$ |
| SF5% | $0.7 \times 10^{-3}$ |
| SF10% | $0.51 \times 10^{-3}$ |
| SF15% | $0.42 \times 10^{-3}$ |
| SF20% | $0.35 \times 10^{-3}$ |
| SF5%+FA30% | $1.8 \times 10^{-3}$ |
| SF10%+FA20% | $0.93 \times 10^{-3}$ |
| SF15%+FA10% | $0.63 \times 10^{-3}$ |

**Table-12 Chloride Permeability Test**

| Mixes | Chloride penetration |
|---|---|
| CVC | 2.1 |
| SCC | 1.24 |
| FA10% | 1.16 |
| FA20% | 1.12 |
| FA30% | 0.9 |
| SF5% | 0.63 |
| SF10% | 0.42 |
| SF15% | 0.32 |
| SF20% | 0.26 |
| SF5%+FA30% | 0.8 |
| SF10%+FA20% | 0.76 |
| SF15%+FA10% | 0.72 |

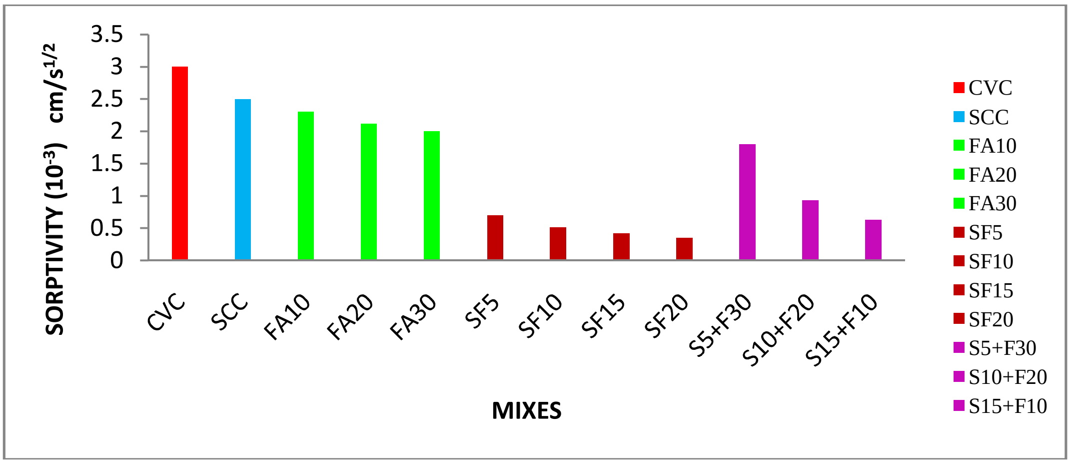


**Fig.10 Mixes Vs Sorptivity**

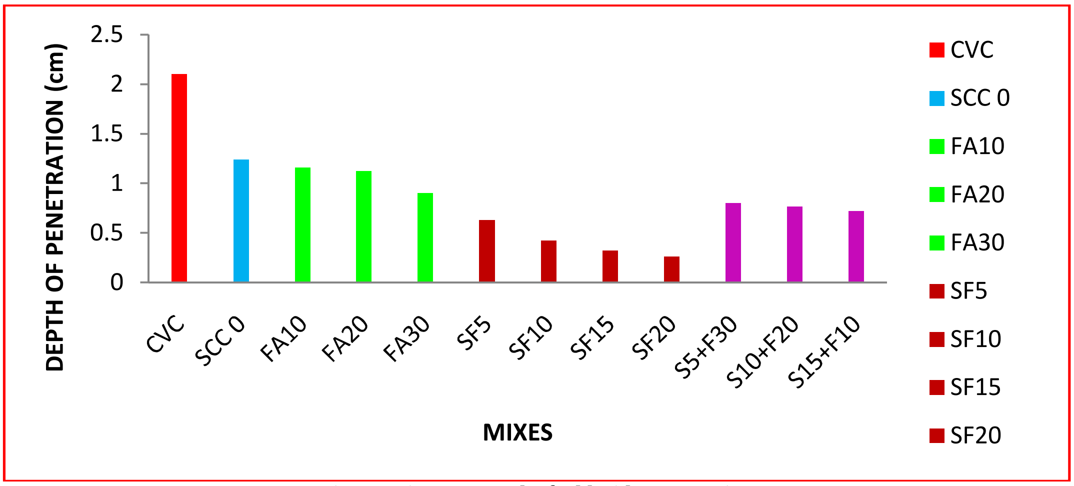


**Fig. 11 Mixes Vs Depth of Chloride Penetration**

## CONCLUSION

Self compacting concrete mix design tool is developed based on the key proportions of the constituents. This tool is very simple and user friendly for the self compacting concrete mix design. As per the mix design addition of Silica Fume and fly ash decreases the demand of HRWRA in SCC Mixes. Replacement of cement by 5%, 10%, 15% and 20% Silica Fume in SCC & Replacement of cement by 10%, 20% and 30% Fly Ash in SCC, the super plasticizer cum retarder demands may be decreased when compare to Controlled SCC.

The SCC with various Partial replacement of cement by Fly Ash and Silica Fume Shows that the 20% replacement of Fly Ash, 15% replacement of Silica Fume and combination of 10% Fly Ash and 15% Silica Fume shows that maximum durability factor.

The SCC with various Partial replacement of cement by Fly Ash and Silica Fume Shows that the 20% replacement of Fly Ash, 15% replacement of Silica Fume and combination of 10% Fly Ash and 15% Silica Fume shows that lower Sorptivity.

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