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DURABILITY STUDIES ON HIGH STRENGTH SELF COMPACTING CONCRETE (SCC)

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ABSTRACT

Self Compacting Concrete (SCC) is the new category of concrete which gets compacted and become dense due to its own self weight. SCC is a High Performance Concrete(HPC) that has excellent deformability and resistance to segregation in its fresh state. The hardened concrete is dense, homogenous and has the same engineering properties and durability as traditional vibrated concrete. It helps in easier placement without vibration or mechanical consolidation.

This paper presents an experimental investigation on the strength characteristics of Self-compacting concrete (SCC) with mineral admixture namely Flyash(FA).The several series of tests involving various binder combinations, water-binder ratio and high range water reducing admixtures and set retarding admixtures were used to optimize the mixture proportions of SCC. Various tests were carried out to study the characteristics of fresh concrete such as Slump flow, U-tube, V-funnel and L-box. For hardened concrete, tests namely compressive strength, split tensile strength, and flexural strength at 7,14 and 28 days were also investigated. Test results shows that the workability characteristics of SCC are within the limiting constraints of SCC. Replacement of Flyash is about 20% by weight of cement. SCC of grades ranging from M30 to M50 were investigated. The maximum compressive strength of SCC for M50 at 28 days age of curing was 52MPa. Then investigations were carried out for Percentage loss in compressive strength, Percentage loss of weights by considering the Durability factors for the specimens immersed in H2So4, HCl and Na2 So4 Solutions for 28 and 56 days and also including the Permeability aspect.

Key Words: *SCC (Self Compacting Concrete), HPC (High Performance Concrete), Fly Ash (FA), Segregation, Workability.*

1. INTRODUCTION

The present day, world is witnessing the construction of very challenging and difficult civil engineering structures. Quite often, concrete being the most important and widely used material is called upon to possess very high strength and sufficient workability properties. Efforts are being made in the field of concrete technology to develop such concretes with special characteristics. Researchers all over the world are attempting to develop high performance concretes.

Self compacting concrete (SCC) was first developed in 1986 in Japan to achieve durable concrete structures. SCC is defined as a category of high performance concrete that has excellent deformability in the fresh state and high resistance to segregation, and can be placed and compacted under its self weight without applying vibration. The use of SCC facilitates the placement process of concrete in densely reinforced members and through restricted sections. Such concrete must achieve excellent deformability, low risk of blockage, and good stability to ensure high filling capacity of the formwork.

SCC has a low yield stress and a moderate viscosity to ensure high filling ability and segregation resistance; proper resistance to segregation is essential to prevent blockage and ensure homogeneous deformation of the concrete through restricted sections. Addition of flyash which is a very fine particle makes the concrete more dense which is a main concern for strength. The resulting concrete is characterized in the fresh state by methods used such as slump-flow, V-funnel, U-box tests and L-box tests respectively.

The successful development of SCC must ensure a good balance between deformability and stability. Researchers have set some guidelines for mixture proportioning of SCC which include (i) reducing the volume ratio of aggregate to cementitious material (ii) increasing the paste volume and water-cement ratio (iii) carefully controlling the maximum coarse aggregate particle size and total volume and (iv) using various viscosity enhancing admixtures. The method for achieving self-compactability involves not only high deformability of paste or mortar, but also resistance to segregation between coarse aggregate and mortar when the concrete flows through the confined zone of reinforcing bars. The resistance to segregation can be enhanced by reducing water-cementitious ratio or by incorporating a viscosity-modifying admixture (VMA). VMA exhibits a greater yield value compared with the concrete without VMA.The mix proportioning of SCC was obtained by changing the paste volume (i.e. powder and water content) with a constant volume of coarse and fine aggregate. Durability was the main concern and the purpose was to develop a concrete mix that would reduce or eliminate the need for vibration to achieve consolidation.

The use of SCC concrete has been increasing in the United States also during the last 5 years. Currently the technology is being primarily applied to the precast industry. Other segments being targeted are flatwork, columns and wall construction. The applications of SCC are many, limited only by the industry's knowledge of it, ability to produce it and acceptance of it.

2. EXPERIMENTAL PROGRAM

The objectives of the experimental study is to,

- To assess flow ability and strength characteristic of self compacting concrete. (SCC).
- Development of concrete mixes with least amount of cement but with a target compressive strength.
- To use the lowest water/powder ratio in the development of self compacting concrete mixes.
- To study the compressive, split and flexural strength at 7,14,28 days.
- To study the durability characteristics of the hardened concrete.

3. MATERIAL PROPERTIES

3.1 Properties of chemical admixtures

- **SUPERPLASTICIZER (GLENIUM B233)**

Property	Range
Color	Light brown liquid
Specific Gravity	1.2
Relative Density at 25°C	1.09 ± 0.01
Chloride ion content	< 0.2%
pH	> 6

- **VISCOSITY MODIFYING AGENT(GLENIUM STREAM 2)**

Property	Range
Color	Colorless free flowing liquid
Relative Density at 25°C	1.01 ± 0.01
Chloride ion content	< 0.2%
pH	> 6

3.2 Properties of mineral admixtures (Fly Ash)

Property	Range
Specific Gravity	2.2

FLY ASH

Fly ash is one of the residues generated in burning, and comprises the fine particles that rise with the flue gases. In an industrial field, fly ash usually refers to ash produced during burning of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipments before the flue gases reach the chimneys.

Fig 1. Fly Ash

Type-II fly ash from Neyveli Lignite Corporation, was used as cement replacement material. The properties fly ash are confirming to I.S. 3812 –1981of Indian Standard Specification for Fly Ash for use as Pozzolana and Admixture.

4. CONCRETE MIX DESIGN

Self-compatibility can be largely affected by the characteristics of materials and the mix proportion. A rational mix-design method for self-compacting concrete using a variety of materials is necessary. The coarse and fine aggregate contents are fixed so that self-compactability can be achieved easily by adjusting the water-powder ratio and super plasticizer dosage only.

In the mix proportioning of conventional concrete, the water-cement ratio is fixed at first from the viewpoint of obtaining the required strength. With self-compacting concrete, however, the water-powder ratio has to be decided taking into account self-compactability because self-compatibility is very sensitive to this ratio

The characteristics of powder and superplasticizer largely affect the mortar property and so the proper water-powder ratio and super plasticizer dosage cannot be fixed without trial mixing at this stage. Therefore, once the mix proportion is decided, self-compactability has to be tested by U-flow, slump-flow and V-funnel test. The four-stage mix design method for SCC has been developed at UPC, Spain which is as follows.

- Determination of optimum dosage of super plasticizer and fillers
- Determination of the aggregate skeleton
- Determination of cement paste based on the requisites at self-compaction and strength

The mix proportions based on the guidelines for Self compacting concrete were as follows:

Coarse aggregate content - 28 to 35 % of volume of mix (270 ~ 360 lit / m^3)
Fine aggregate content - 48% to 55% of total wt of aggregate
Paste volume - 60% of mortar volume
Powder volume - 50% of paste volume (300 ~ 380 lit / m^3)
Water content - 50% of paste volume (150 ~ 210 lit / m^3)
Super plasticizer - 4% of cementitious material
Water/powder ratio - 0.80 to 1.00 by volume
Total power content - 160 to 240 litres (400-600 kg) per m^3

Table-1 shows the mix proportion for various mixes

Component	M30	M35	M40	M45	M50
Cement (Kg)	385.06	391.49	392.92	397.43	400.78
Fly ash (Kg)	131.39	133.58	134.07	135.607	136.755
Fine aggregate (Kg)	900.74	915.79	883.08	888.19	865.41
Coarse aggregate (Kg)	799.876	769.692	799.88	814.97	799.876
Water (lit)	173.28	172.255	165.03	158.972	156.304
Super plasticizer (lit)	3.10	3.15	3.16	3.2	3.225

W/c ratio	0.45	0.44	0.42	0.4	0.39
W/p ratio	1	1	1	1	1

5. FRESH PROPERTIES OF SELF COMPACTING CONCRETE

There are three distinct fresh properties which essentially define SCC and which are fundamental to its performance both in the plastic and hardened state. They are

- **Filling Ability:** The property of a SCC to fill all the corners of the formwork under its own weight.
- **Passing Ability:** The property of SCC to flow through reinforcing bars without segregation or blocking.
- **Resistance to segregation:** The property of SCC to flow without segregation of aggregates.

TESTING OF FRESH PROPERTIES OF SCC

A number of test methods such as slump flow test, V-funnel, U-box and L-box test are in used to evaluate the fresh concrete properties of SCC.

5.1 Slump Flow test:

Workability of ordinary concrete is primarily governed by its water content where as the workability of SCC is determined by the chemical and mineral admixtures used. The setting time of SCC is slightly higher than that of conventional concrete. If required, retarders and set accelerators can be used to control the setting times.

The simplest and most commonly adopted test method for evaluating self-compatibility quality of SCC is slump flow test (Fig.-1). This test consists of measurement of mean diameter of concrete flowing out of the slump cone after the concrete has stopped flowing. The slump flow was used to assess the horizontal free flow and the filling ability of SCC in the absence of obstructions. It's typical range is between 650 to 800mm.

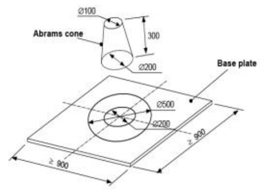


Fig-2. Slump flow test apparatus

5.2 V – funnel Test

The apparatus consists of a V shaped funnel with rectangular cross section as shown in Fig. 4. The concrete is poured into the funnel with the gate blocking the bottom opening. When the funnel is completely filled, the bottom gate is opened and the time for the concrete to flow out of funnel is noted. This is called “Flow Time”. Flow time is between 8~ 12 sec is recommended for a concrete to qualify as SCC.This test measures the ease of flow of the concrete; shorter flow times indicate greater flow ability.

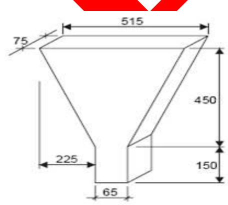


Fig-3. V-funnel test apparatus

5.3 U-tube Test

This test examines the behaviour of concrete in the simulated field conditions. The U-tube test gives an indication of the resistance of mixture to flow around the obstruction in a U-tube mould. This test also detects the tendency of coarse aggregate particles to stay back or settle down when the mixture flows through the closely spaced reinforcement. If the filling height is more than 70% of the tube it is considered as SCC. This test is used to optimize percentage of aggregate content required in total volume of concrete. This test measures filling and segregation properties of SCC.

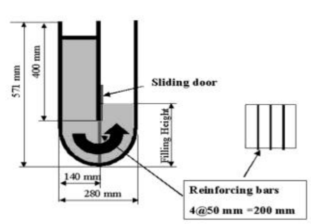


Fig-4.U-tube test apparatus

5.4 L-box Test

L-box test apparatus consists of a vertical and horizontal section. Reinforcing bars are placed at the intersection of two sections of the apparatus as shown in fig. 3. In general, the gap between the reinforcing bars kept at 35 and 55mm for 10mm and 20mm coarse aggregate respectively. The time taken by the concrete to flow a distance of 200mm and 400mm in the horizontal section of the apparatus after the opening of the gate from the vertical section is measured. The L-box test gives an indication of the filling, passing and segregation ability of the concrete. Typical range of values for h2 / h1 = 0.8 ~ 1

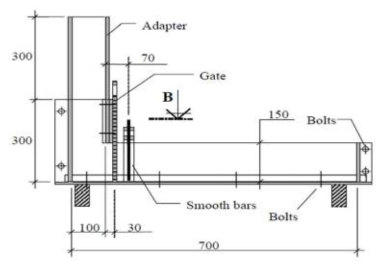


Fig-5. L-box test apparatus

Table-2 shows the test results obtained for fresh concrete of various mix proportions

Mix Designation	M30	M35	M40	M45	M50	Range	
						Min	Max
Slump flow (cm)	70	72	75	72	69	65	80
V-funnel flow time (Sec)	9	10	11	10	8	8	12
V-funnel T5min (sec)	1	2	2	3	1	0	3
L-Box (Blockage ratio)	0.9	0.9	0.8	0.9	0.8	0.8	1
U-Tube (% passing)	82.3	89.7	85.9	88.2	83.1	70	> 70

6. TEST ON HARDENED CONCRETE

The mechanical properties of self-compacting concrete are similar to conventional concrete. The homogeneity of self-compacting concrete can be analyzed through scanning electron microscopy. Tests like compression test, split tensile test and flexural strength were conducted as per IS specifications. These tests were conducted for specimens at 7, 14 and 28 days and the results were tabulated as follows:

Table 3 : Compressive strength test results for various proportions

Mix	7days strength (N/mm^2)	14days Strength (N/mm^2)	28days Strength (N/mm^2)
M30	17	26.4	34.3
M35	19.2	30.4	38.6
M40	22.8	37.6	45.4
M45	24.5	39.2	48.6
M50	26.2	42	52.5

Table 4 : Split tensile strength test results for various proportions

Mix	7days Strength (N/mm^2)	14days Strength (N/mm^2)	28days Strength (N/mm^2)
M30	1.7	2.64	3.4
M35	1.91	3.02	3.8
M40	2.2	3.75	4.33
M45	2.45	3.9	4.8
M50	2.6	4.18	5.31

Table 5 : Flexural strength test results for various proportions

Mix	7days Strength (N/mm^2)	14days Strength (N/mm^2)	28days Strength (N/mm^2)
M30	2.34	3.536	4.42
M35	3.24	4.13	4.72
M40	3.6	4.59	5.08
M45	3.68	4.7	5.41

M50	3.83	4.85	5.67

6.1 Comparative Study for Compressive Strength

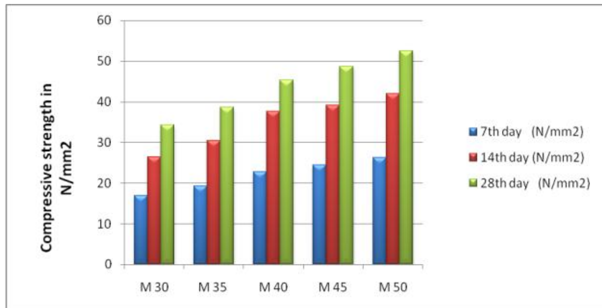


Fig 6. Compressive Strength

6.2 Comparative Study for Split Tensile Strength

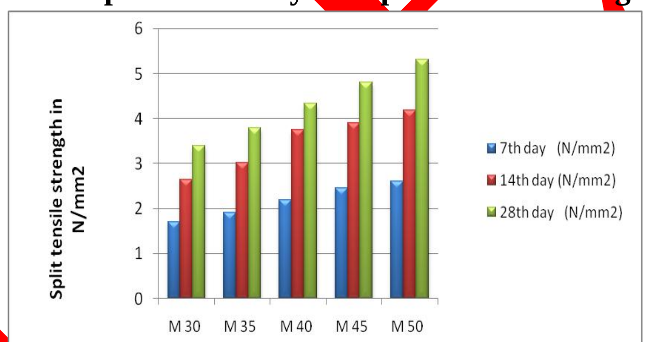


Fig 7. Split Tensile Strength

6.3 Comparative Study for Flexural Strength

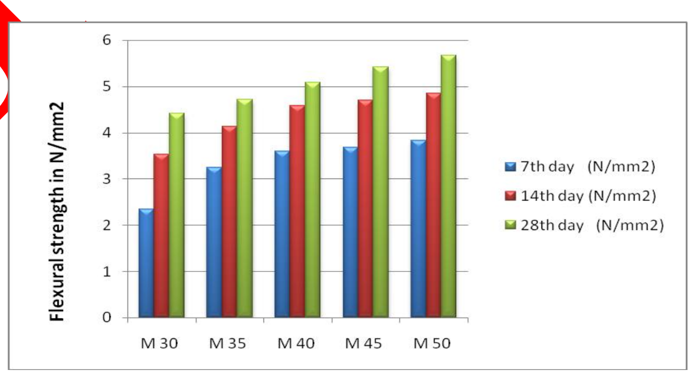


Fig 8. Flexural Strength

7. DURABILITY STUDIES ON HARDENED SCC

- Durability of the cement concrete is defined as the ability to resist weathering action, chemical attack, abrasion or any other process of deterioration.
- The durability of a concrete structure is associated to the permeability of the surface layer, it should limit the ingress of substances that can initiate or propagate possible deleterious actions (CO_2, chloride, sulphate, water, oxygen, alkalis, acids, etc.)

DURABILITY TESTS

7.1 ACID RESISTANCE TEST

- The cubes of size 150mm*150mm*150mm will casted and gets cured for 28 days.
- The initial weight of cubes after 28 days will be taken as (W1).
- After that the cubes are immersed in 5% by weight of water of diluted hydrochloric acid (HCl) with pH value of 2 for a period of 28 days.
- The concentration of this solution should be maintained throughout this period.
- After 28 days the cubes will taken from acid water and the surfaces should be cleaned well and weight will recorded as (W2).
- The compression strength of the cubes should be calculated.
- The loss in compressive strength and the improvement of resistance of acid attack of the concrete cubes should be calculated.
- % reduction in weight is also calculated.

7.2 ALKALINE RESISTANCE TEST

- The cubes of size 150mm*150mm*150mm will casted and gets cured for 28 days.
- The initial weight of cubes after 28 days will be taken as (W1).
- After that the cubes are immersed in 5% by weight of water of sodium hydroxide (NaOH) for a period of 28 days.
- The concentration of this solution should be maintained throughout this period.
- After 28 days the cubes will taken from alkaline water and the surfaces should be cleaned well and weight will recorded as (W2).
- The compression strength of the cubes can be calculated.
- The loss in compressive strength of the concrete cubes should be calculated.

- % reduction in weight is also calculated.

7.3 SULPHATE RESISTANCE TEST

- The cubes of size 150mm*150mm*150mm will casted and gets cured for 28 days.
- The initial weight of cubes after 28 days will be taken as (W1).
- After that the cubes are immersed in 5% by weight of water of sodium sulphate (Na_2SO_4) and 5% of magnesium sulphate ($MgSO_4$)for a period of 28 days.
- The concentration of this solution should be maintained throughout this period.
- After 28 days the cubes will taken from solution. The surfaces should be cleaned well and weight will recorded as (W2).
- The compression strength of the cubes can be calculated, the changes in strength of cubes should be found.
- % reduction in weight is also calculated.

7.4 WATER ABSORPTION TEST

- Standard cubes of size 150 x 150mm x 150mm
- Curing Period 28 days.
- The initial weight of cubes after 28 days is taken as W1.
- Then the cubes are placed in the oven at 110 degree Celsius till they attain a constant weight.
- After taking out from the oven the weight of the cube is once again noted as W2.
- Then the specimens is placed in clean water for a period of 24 hours.
- The increase in weight as a percentage of the original weight is expressed as its absorption.(in%)
- The average absorption of the specimen shall not be greater than 5% with no individual unit greater than 7%.

Fig 9 Variation in compressive strength of cubes for acid resistance test

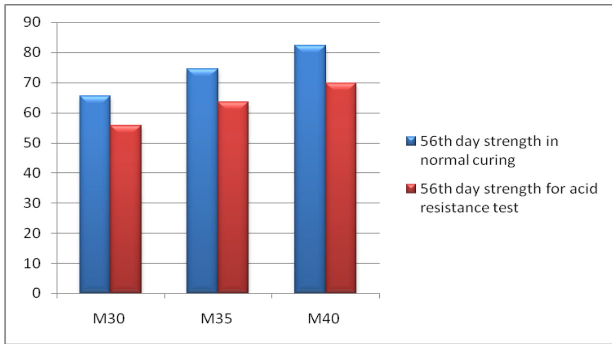


Fig 10 Variation in compressive strength of cubes for alkaline resistance test

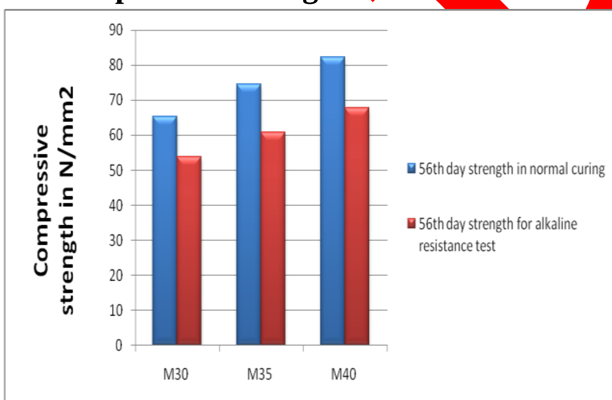
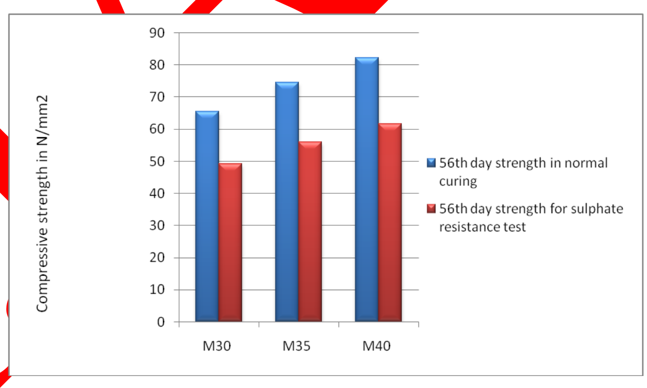


Fig 11 Variation in compressive strength of cubes for sulphate resistance test



8. CONCLUSION:

Based on the experimental investigation, the following conclusions were drawn from the test results:

- The test results for fresh concrete are within the limits of SCC i.e., flowability, passing ability and resistance against segregation.
- The self-compacting high performance concrete of M50 grade for 7 days compressive strength is 26.2. MPa and 28 days strength of 52.5 MPa has been obtained with a water-cement ratio of 0.40
- The flow of slurry is comfortable with better cohesive fluid state
- The additional cost on account of chemical admixture in self compacted concrete is offset by the cost savings by minimizing cement.
- Based on the experimental investigation it was observed that the self compacting concrete gives a homogeneous and cohesive mix with marginal decrease in workability.
- Durability properties of the mixes are under investigation.

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