Mechanical and Durability Properties of Self Compacting Concrete

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***Abstract**: The Self Compacting Concrete (SCC) was to be the future in the construction industry. To reduce the amount of cement in the concrete mix, fly ash was replaced in the SCC mix. The study deals with reducing the cement content in the SCC mix with replacement of 15%, 20% and 25% of fly ash. The concrete mix includes four mixes with one conventional mix and three mixes with replacement of fly ash instead of cement with different percentage. With the addition of Superplasticizers and Viscosity modifying agent (VMA) the concrete mix enriches the quality of workability in this study. The SCC thus generated was subjected for testing the mechanical and durability properties of the concrete. The testing includes compressive strength, split tensile test, flexural testing and rapid chloride penetration test. The result concludes, compared to the replacement of fly ash with the percentage of 25% and 20% the concrete mix with replacement of fly ash with 15% gives greater strength and more durable.*

Keywords - Self-Compacting Concrete, Fly ash, Super plasticizer, Viscosity modifying agent

I. INTRODUCTION

The use of Self Compacting Concrete (SCC) was enriched nowadays. Due to the voids present in the conventional concrete there may have chances in forming cracks on the structural member due to high autogenous shrinkage values. Since SCC was homogeneous, therefore due to the presence of micro particles the voids in the concrete gets minimized and therefore the shrinkage gets neglected. SCC gets compacted by its own weight majorly used in congested reinforcement. In our study fly ash was to be used for the replacement of cement. Fly ash is the byproduct of coal combustion process for energy generation, and is recognized as an environmental pollutant [1]. In India, thermal power plants are majorly reliant on the combustion of high- ash bituminous coal in pulverized fuel fired systems. The fly ash was going to be replacing the construction industry soon [2]. By means of using SCC, problems like detachment, bleeding, water absorption and permeability can be avoided. SCC mix design and structure is not significantly different from the normal concrete. In addition, special precautions regarding aggregate gradation used in this type of concrete considered [3]. Since, the aggressive compounds play a major role in the mix. Dense fly ash concrete enhances the aggressive compound on the surface; thereby the destructive action is reduced. Fly ash is highly resistant to sulfate attack, milk acid and sea water [4]. Usage of super plasticizer is a key factor for SCC, which leads to reduction of water content up to 30% without affecting the workability. The viscosity modifying agent was used to improve the cohesiveness and stability of SCC [5].

Objective of this study

- To study the mechanical and durable properties of SCC with replacement of fly ash instead of cement.
- Replacement includes about 15%, 20% and 25% of fly ash.
- Comparative study for the replacement of fly ash in the mix.

II. MATERIALS

A. Cement

Cement used for this study was ordinary Portland cement of grade 53.

B. Coarse Aggregate

Usually for SCC coarse aggregate size of range 10-12 mm was used, aggregates should be uniform in size [6]. In our study we used 10mm size of coarse aggregate content throughout the study. To find the finesses modulus and grain size distribution the sieve analysis of coarse aggregate was conducted.IS sieves size of 80mm, 40mm, 20mm, 10mm, 4.75mm, 2.36mm, 1.18mm, 600µ, 300µ and 150µ as per IS: 2386 (Part I) – 1963. Table 1 implies the sieve analysis result of coarse aggregate.

Table 1: Sieve Analysis Result of Coarse Aggregate.

IS Sieve	Weight retained (g)	Cumulative Weight Retained	Cumulative % Retained	Cumulative % passing
80mm	0	0	0	100
40mm	0	0	0	100
20mm	123	123	6.15	93.85
10mm	1866	1989	99.45	0.55
4.75mm	10	1999	99.95	0.05
2.36mm	1	2000	100	0
1.18mm	0	2000	100	0
600µ	0	2000	100	0
300µ	0	2000	100	0
150µ	0	2000	100	0

Fineness modulus of Coarse Aggregate = $\sum$ (Cumulative % Retained) = 706/100 =7.06

Bulk Density of Coarse Aggregate = 1631kN/m^3

C. Fine Aggregate

SCC needs more powder content when compared to conventional concrete. In our study we used river sand as fine aggregate during the study. To find the finesses modulus and grain size distribution the sieve analysis of fine aggregate was conducted.IS sieves size of 4.75mm, 2.36mm, 1.16mm, 600µ, 300µ and 150µ as per IS: 2386 (Part I) – 1963. Table 2 implies the sieve analysis result of fine aggregate.

Table 2: Sieve Analysis Result of Fine Aggregate.

IS Sieve	Weight retained (g)	Cumulative Weight Retained	Cumulative % Retained	Cumulative % passing
4.75mm	0.074	7.4	7.4	92.6
2.36mm	0.120	12	19.4	80.6
1.18mm	0.155	15.5	34.9	65.1
600µ	0.146	14.6	49.5	50.5
300µ	0.082	8.2	57.7	42.3
150µ	0.155	15.5	73.2	26.8

Fineness modulus of Fine aggregate = $\sum$ (Cumulative % Retained) = 242.1 /100 = 2.421

Bulk Density of Fine Aggregate = 1.86kN/m^3

D. Specific Gravity

The specific gravity of the materials used in this study was tabulated below in the table 3.

Table 3: Specific Gravity of material to be used in the Concrete mix

Materials	Specific Gravity
Coarse Aggregate	2.765
Fine Aggregate	2.7
Cement	3.12
Fly ash	2.20

E. Fly Ash

The study is in fond of pozzolanic material, thereby using fly ash we enrich the concrete behaviour. The structure of fly ash was spherical which makes them free flow on concrete mixtures. The durability of the concrete gets increased due to the addition of fly ash through control of high thermal gradients [7]. Class F fly ash was used due to the presence of pozzolanic material.

F. Chemical Admixture

The homogeneity of concrete will be affected when cement mixes with water. Therefore a chemical admixture was used, the superplasticizers or plasticizers are used for reducing the water content and it is termed as water reducing agents. To reduce the coarse content and to increase the fine content in the concrete mix there needs a proper workability and henceforth superplasticizers are used [8]. The amount of super plasticizer to be added was based on the weight of cement and varying water cement ratio which ranges from 0%, 2%, 2.5%, 3.5% and 0.4, 0.45, 0.5, 0.55 respectively [9]. The master glenium is used for this study as super plasticizer [10] [11] [12] [13]. The properties of master glenium were presented in the table 4.

Table 4: Properties of Master Glenium

Aspect	Light brown liquid
Relative Density	1.10 ± 0.01 at 25°C
pH	≥6
Chloride ion content	<0.2%

F. Viscosity Modifying Agent

The rheological properties of the concrete mix were stabilized by the addition of viscosity modifying agent (VMA). The VMA will influence the viscosity and thickens the concrete mix which makes concrete free from segregation. VMA does not change any properties of the mix instead of being viscous [14]. The Glenium stream 2 was used as VMA in our study, it have a high segregation resistance, ensures good consistency of the mix and maintains stability in the concrete with sufficient fluidity [14]. The properties of glenium steam 2 were presented in the table 5.

Table 5: Properties of Glenium Stream 2

Appearance	Colorless free flowing liquid
Relative Density	0.01 at 25° C
pH	≥6
Chloride ion content	<0.2%

III. Mix Proportion

The mix consists of replacement of fly ash instead of cement with a percentage of 15%, 20% and 25%. A total of four mixes were prepared for this study. A conventional concrete without the addition of fly ash and the remaining three mixes includes the replacement of fly ash. The mix followed throughout the project was M40 grade of concrete. The concrete mix that to be followed in this study were calculated and tabulated in the Table 6.

Table 6: Concrete Mix

Materials	Conventional Concrete (Mix 1)	Replacement of Fly Ash		
		15 %(Mix 15%)	20% (Mix 20%)	25 %(Mix 25%)
Cement	520	442	416	390
Fly Ash	-	78	104	130
Water/ Binder	0.45	0.45	0.45	0.45
Fine aggregate	870	870	870	870
Coarse aggregate	890	890	890	890
Super Plasticizer	0.26	0.26	0.26	0.26
VMA	0.053	0.053	0.053	0.053

IV. Tests on Fresh Concrete

If there obtained a satisfactory mix design the test to be conducted using fresh concrete should have been done. An SCC mix gets satisfied whenever it has the following characteristics [15].

- Filling ability
- Passing ability and
- Segregation Resistance

For the above characteristics there are several test methods which was followed widely. In our study we used L- box test, V- funnel test, V- funnel test at T_5 minutes, slump flow and $T_{50\ cm}$ slump flow. L-box test was used to determine the passing ability of the concrete, V-funnel and V-funnel test at T_5 minutes were used to determine the segregation resistance of the concrete mix, Slump flow and T_{50} Slump test were conducted to determine the filling ability of the concrete mix. Results of Tests conducted on Fresh Concrete were tabled in the table 7.

Table 7: Results of Tests conducted on Fresh Concrete

Tests	Tests Values
Slump Flow	750mm
$T_{50\ cm}$ Slump Flow	3sec
V- funnel	9sec
V- funnel at T_5 minutes	2sec
L- box	0.9 (h_2/h_1)

Preparation of Test Specimen

A total of 36 cubes (150 mm), 4 cylinders (50 mm diameter and 200mm height), 8 cylinders (70mm diameter and 150 mm height) and 8 beams (100*100*400mm) were casted in this study. After the specimen was filled with concrete mix and later it was subjected to curing.

V. Tests on Hardened Concrete

A. *Compressive Tests on Cubes*

The compression test was carried out on standard 150*150*150mm cubic specimens. All the cubes were tested in surface dried condition for each mix combination, three cubes were tested at the age of 14, 28 and 56 days using compression testing machine of 100 ton capacity. The tests were carried out at a uniform stress rate, after the specimen was centred in the testing machine. The loading was continued till the specimen reaches its ultimate load. The ultimate load divided by the cross sectional area of the specimen is equal to the ultimate compressive strength. Figure 1and Figure2 shows the tested specimens.

Figure 1: Compressive Test on Specimen

Figure 2: Tested Specimen

Table 8: Result of Compressive strength on 14th Day

No	Mix	Compressive Strength after 14 Days Mpa	Average Compressive Strength after 14 Days Mpa
1	Mix 1	37.4	31.17
		26.5	
		29.61	
2	Mix 15%	51.42	43.61
		48.49	
		30.92	
3	Mix 20%	40.25	34.12
		30.95	
		31.15	
4	Mix 25%	33.26	31.53
		37.01	
		24.32	

Table 9: Result of Compressive strength on 28th Day

No	Mix	Compressive Strength after 28 Days Mpa	Average Compressive Strength after 28 Days Mpa
1	Mix 1	43.21	41.19
		38.27	
		42.09	
2	Mix 15%	47.5	53.83
		53.5	
		60.5	
3	Mix 20%	47.7	47.56
		41.85	
		53.13	
4	Mix 25%	39.1	42.52
		42.03	
		46.46	

Table 10: Result of Compressive strength on 56th Day

No	Mix	Compressive Strength after 56 Days Mpa	Average Compressive Strength after 56 Days Mpa
1	Mix 1	47.32	46.97
		48.19	
		45.41	
2	Mix 15%	58.98	56.22
		58.87	
		50.81	
3	Mix 20%	43.36	45.22
		49.04	
		43.26	
4	Mix 25%	54.25	52.17
		39.83	
		62.44	

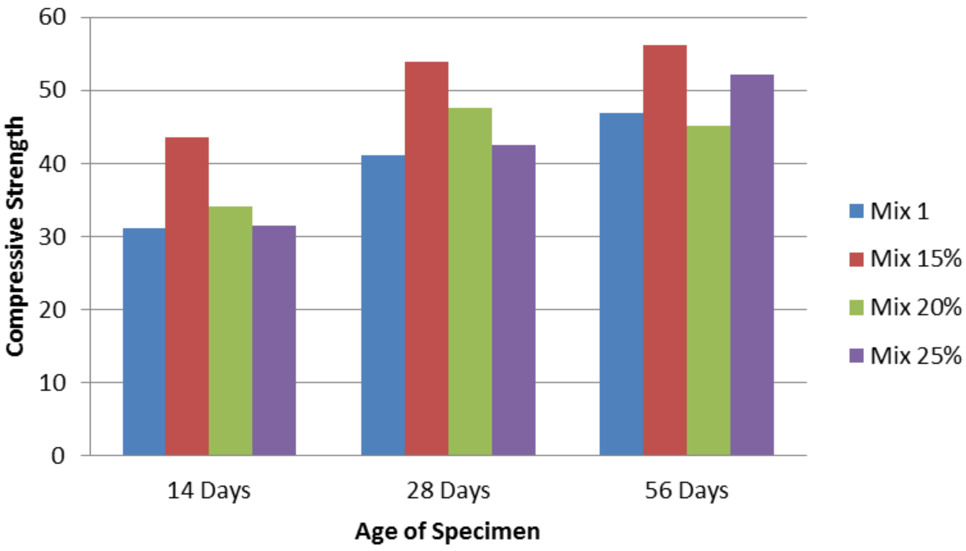

Figure 3: Comparison of Compressive strength of Concrete specimen on different days

Figure 3 implies the comparison between all the test cube concrete specimens which undergoes for compression testing. The graph implies that the concrete mix which was subjected to 15% replacement of fly ash instead of cement shows greater compressive strength of concrete than the concrete mix of conventional concrete, 20% replacement of fly ash and 25% replacement of fly ash.

Table 11: Result of Split Tensile Strength

Testing time	Mix	Average Split Tensile Strength of two samples (N/ mm^2)
56 days	Mix 1	6.08
56 days	Mix 15%	6.51
56 days	Mix 20%	6.05
56 days	Mix 25%	5.43

B. *Split Tensile Strength*

The cylinders were tested in saturated surface dried condition. For each mix combination, two cylinders were tested at the age of 56 days using compression testing machine of 100 ton capacity. The tests were carried out at a uniform stress rate, after the specimen was centred in the testing machine. The loading was continued till the specimen reaches its ultimate load. Figure 4 and figure 5 imply the split tensile strength that tested. The results of split tensile strength test were tabled in the table 11.

Figure 4: Split Tensile strength test

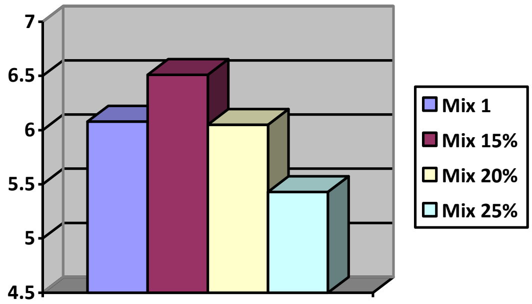

Figure 5: Split tensile strength for various mixes

Figure 5 infers the split tensile strength of the concrete specimen cylinder. In this graph 15% replacement of fly ash instead of cement shows superior strength compared to other mixes.

C. Flexural Test

Flexural test was carried out on a beam specimen with dimension 400*100*100mm at the age of 56 days. Two point loading was given to the specimens and the flexural load was recorded at time of failure.

Figure 6: Flexural Testing

Table 12: Result of Flexural Beam Strength Test

Testing time	Mix	Average Flexural Beam Strength of two samples (N/ mm^2)
56 days	Mix 1	6.68
56 days	Mix 15%	6.66
56 days	Mix 20%	7.96
56 days	Mix 25%	8.97

The result concludes that concrete mix replacement of 25% of fly ash instead of cement shows greater flexural quality when compared to other concrete mixes.

D. Rapid Chloride Penetration Test (RCPT)

The test method involves obtaining a 100mm diameter core or cylinder sample from the concrete being tested. A 50 mm specimen is cut from the sample [16]. The side of the cylindrical specimen is coated with epoxy and after the epoxy is dried, it is put in a vacuum chamber for 3 hours. The specimen is vacuum saturated for 1 hour and allowed to soak for 18 hours. It is then placed in the test device. The left hand side (-) of the test cell is filled with a 3% NaCl solution. The right- hand side (+) of the test cell is filled with 0.3N NaOH solution. The system is then connected and a 60 volt potential is applied for 6 hours. Readings are taken every 30 minutes. At the end of 6 hours the sample is removed from the cell and the amount of coulombs passed through the specimen is calculated. To determine the average charge passed (Coulombs) in the specimen a formula was used to analyse the test was mentioned in the below.

$$Q = 900 (I_0 + 2I_{30} + 2I_{60} + ... + 2I_{300} + 2I_{330} + I_{360})$$

Figure 7: Loaded Cell

Figure 8: RCPT

Table 13: Readings of RCPT

Time	Mix 1 Top	Mix 1 Middle	Mix 15% Top	Mix 15% Middle	Mix 20% Top	Mix 20% Middle	Mix 25% Top	Mix 25% Middle
I_0	98	112	114	145	92	112	78	88
I_{30}	99	121	124	169	94	121	84	96
I_{60}	101	129	133	173	95	125	85	97
I_{90}	104	134	138	182	95	131	87	104
I_{120}	110	140	148	186	98	142	89	108
I_{150}	112	149	152	188	102	144	90	114
I_{180}	115	151	162	196	104	146	92	115
I_{210}	117	152	164	204	118	152	92	119
I_{240}	118	153	164	206	130	152	92	123
I_{270}	120	154	166	213	136	153	92	125

I_{300}	122	161	167	215	141	154	93	125
I_{330}	124	163	173	219	148	165	94	129
I_{360}	125	168	175	221	152	166	95	131
Q	2436.3	3150	3303.9	4201.2	2489.4	3103.2	1937.7	2456.1
Q Avg	2793.15 coulombs		3752.55 coulombs		2796.3 coulombs		2196.9 coulombs	

Table 14: Result of RCPT

Mix	Average Charge Passed (Coulombs)	Chloride ion permeability
Mix 1	2793.15	Moderate
Mix 15%	3752.55	Moderate
Mix 20%	2796.3	Moderate
Mix 25%	2196.1	Moderate

VI. CONCLUSION

Based on the test results, the addition of fly ash to the mixture containing hydraulic lime is quite beneficial, bringing a substantial improvement of the behaviour of SCC. SCC with 15% replacement of cement with fly ash showed good results both in compression and split tensile. In terms of tension the values varies at micro level but in terms of compressive strength, 15% replacement of fly ash considerably shows greater strength when compared to other mix. Since concrete should be good in compression therefore it was preferred. From the experimental investigation it is clear that cement can be replaced with 15% of fly ash effectively in SCC, thereby reducing the consumption of cement, which in turn reduces the cost. In terms of rapid chloride penetration test results 15% replacement of fly ash suffers from chloride penetration.

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