EXPERIMENTAL STUDIES ON GLASS FIBRE REINFORCED SELF COMPACTION CONCRETE

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ABSTRACT

Self-Compacting Concrete (SCC) is able to flow under its own weight and completely fill the formwork, even in the presence of congested reinforcement, without any compaction, while maintaining homogeneity of the concrete. Compaction is difficult to be done in conditions where there are dense reinforcement and large casting area. Usage of SCC will overcome the difficult casting conditions and reduce manpower required. Addition of fibres will enhance the tensile and ductile behaviour of concrete with brittle nature. SCC was added with relatively short, discrete, and discontinuous glass fibers to produce Glass Fibre Reinforced Self Compacting Concrete (GFRSCC). The purpose of this study is to investigate the workability and mechanical properties of plain SCC and GFRSCC. The laboratory testing included slump flow test, L-Box test, sieve segregation resistance test, density test, ultrasonic pulse velocity (UPV) test, compressive strength test, splitting tensile strength test, and flexural strength test. The dosage of super plasticizer required increased as fibre content increased. There has been a lack of studies for productivity improvement in the construction industry. A review of literature was done where an inventory of productivity related factors was found and interpolated with test results.

Keyword: - *Self-Compaction Concrete, Glass Fibres, Productivity Improvement, Glass Reinforced Self-compacting concrete (GFRSCC), Compressive Strength, Flexural Strength, Split Tension Test, and Concrete.*

1.INTRODUCTION

Production of durable cement concrete at the construction site is still a very big challenge for the construction industry despite various technological advancements. For producing durable concrete proper compaction is necessary which helps to reduce the voids in the concrete. However it is not done in most of the construction sites leading to poor quality of concrete. Compaction is done using vibration from power equipment which leads to highly undesirable noise, increased construction time and labour and sometimes injurious to workers. Hence to overcome all these difficulties Self-Compacting Concrete (SCC) was developed in Japan in the late 1980s as a solution to achieve durable concrete structures independent of the quality of construction work.

SCC can be considered as a concrete with high flowability that can be placed and compacted under its own weight without any external vibration, assuring complete filling of formworks and also the complete covering of the reinforcing bars even when the space between the reinforcements is very narrow. SCC is characterized by high flowability in its fresh state and increased strength in its hardened state because of a compact matrix structure. SCC has many advantages that include faster construction, better surface finishes, easier placing, reduction in noise levels and improved durability.

The term Fibre Reinforced Concrete (FRC) can be defined as a concrete structure having randomly oriented and dispersed fibres. Fibres can be defined as small wire-like reinforcements which are made of either steel or polymers having high ductility. The fibres are produced in a wide range of sizes and shapes, stiff or flexible etc. Addition of fibres into concrete improves the overall ductility of the concrete imparting toughness, greater tensile strength, and resistance to fatigue, impact, blast loading and abrasion. Fibres are added not only to improve the ductility of concrete but also, more importantly to control the cracking, by the bridging of the fibres across the cracks, which delay the propagation and widening of localized cracks.

The use of glass fibres in SCC might bring together the advantages of both fibres and SCC. Glass Fibre Reinforced Self-Compacting Concrete (GFRSCC) combines theadvantages of SCC in its fresh state and that of fibres in its hardened state. Because of the superior performance of SCC in its fresh state, addition of fibres will lead to a more uniform dispersion of fibres which is very critical for the performance of any fibre reinforced composite. Also the compactness of SCC matrix due to higher amountof finer particles may improve the interface zone properties and consequently the fibre-matrix bond leading to enhanced post-cracking toughness and energy absorption capacity.

1.1 NEED FOR STUDY

The addition of glass fibres may impart superior mechanical properties to concrete; however its addition causes negative impact on its workability makingmixing and placing very difficult. Although the use of fibres in SCC might reduce the issues associated with workability to some extent, it affects the self-compacting abilities of the SCC. Hence it becomes necessary to determine the possibility of producing SCC with the addition of a considerable quantity of fibres and study the fresh and hardened state properties of the GFRSCC.

1.2 SCOPE OF STUDY

The scope of this project is to produce SCC using S-Glass fibre and to studythe fresh and hardened state properties of GFRSCC

1.3 OBJECTIVE OF STUDY

The primary objective of this experimental work is,

1) To determine the maximum dosage of fibres that can be addedwithout compromising the flow characteristics of the self-compacting concrete.

2) To study the effective utilization of glass fibre in self-compactingconcrete by conducting the following tests.

- Workability
- Compressive strength
- Flexural strength
- Split tensile strength

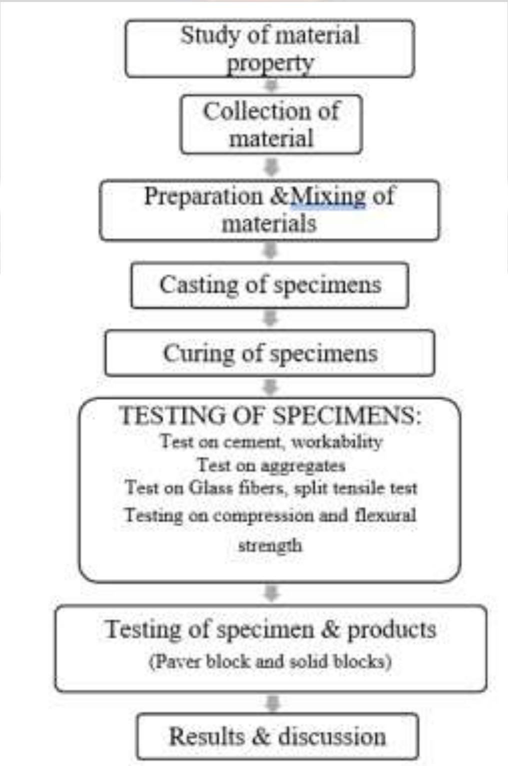
3) To study the durability characteristics of GFRSCC by conducting thefollowing tests.

- Water absorption
- RCPT

4) To compare the properties of the proposed GFRSCC with that ofexisting conventional SCC.

2. METHODOLOGY

A Simple flow chart showing the sequence of activities carried out throughout the project:



3. Properties of materials

Table 3.1 Properties of coarse aggregate

S.No	Properties	Values
1	Specific gravity of C.A	2.71
2	Bulk Density in loose state	1346.7 kg/m³
3	Bulk Density in compacted state	1480.07 kg/m³
4	Crushing strength	19.93%
5	Impact strength	8.97%

Table3.2 Properties of fine aggregate

S. No	Properties	Values
1	Specific gravity	2.45
2	Bulk Density in loose state	1294.87 kg/m³
3	Bulk Density in compacted state	1442.16 kg/m³
4	Fineness Modules	3.2
5	Zone	II

Table 3.3 Properties of Cement

S. No	Properties	Values
1	Specific gravity	3.15
2	Consistency	31%
3	Initial setting time	40 minutes
4	Final setting time	300 minutes

Table 3.4 Composition of OPC53 grade cement

S .No	Properties	Cement values	Requirements as per IS12269-1987
1	Lime saturation factor	0.9	0.8-1.02
2	Alumina Modulus	1.23	0.66 (min)
3	Insoluble residue (%)	0.25	4 (max)
4	Magnesia (%)	1.1	6 (max)
5	Sulphuric anhydride SO_3 (%)	1.5	3 (max)
6	Loss on ignition (%)	0.8	4 (max)
7	Alkalies	-	-
8	Chloride (%)	0.002	0.1 (max)
9	C_3A Content	7	-
10	Temperature during Testing	27±2	27±2
11	Humidity (%)	65±5	65±5

Table 3.5 Chemical composition of Class-F Flyash(As per ASTM C618)

S .No	Compound	Content in % of weight
1.	Silicon di oxide, SiO_2	59
2.	Alumina, Al_2O_3	21
3.	Iron Oxide, Fe_2O_3	3.7
4.	Calcium Oxide, CaO	6.9
5.	Magnesium Oxide, MgO	1.4
6.	Sulphur Trioxide, SO_3	1
7.	Potassium Oxide, K_2O	0.9

Table 3.6 Physical Properties of Class-F Flyash

S.No.	Properties	Value
1.	Colour	Whitish Grey
2.	Bulk Density (g/cm^3)	0.994
3.	Specific Gravity	2.288
4.	Moisture	3.14%
5.	Average particle size (µm)	6.94

Table 3.7 Physical properties of S-Glass fibre

Type	Tensile strength (MPa)	Compressive strength (MPa)	Density (g/cm3)	Thermal expansion (µm/ºc)	Softening temperature (ºc)
S-GLASS	4890	1600	2.46	2.9	1056

Table 3.8 Chemical Composition of S-Glass fibre

SiO_2	Al_2O_3	MgO
65%	25%	10%

4. TESTS FOR FRESH PROPERTIES OF SCC

Several test methods have been developed in attempts to characterize the fresh properties of SCC. So far there is no single test is capable of assessing all of the key parameters of SCC. The European Federation of Specialist Construction Chemicals and Concrete Systems (EFNARC) give the list of test methods for workability properties of SCC.

They are characterized by a combination of tests such as Slump Flow, V- Funnel, L-Box, U-Box, J-Ring test, Filling Box Test, Column Segregation etc. Most of these methods merely serve as guidelines and recommendations and have not been internationally standardized. These test methods and values are stated for maximum aggregate size of up to 20 mm. For other aggregate sizes different test methods or different equipment dimensions may be used.

Table 4.1 Recommended Limits for Different Properties of SCC

S.No.	Property	Range	Property
1.	Slump Flow Diameter	500-700 mm	Filling ability
2.	T_{500mm}	2-5 sec	Filling ability
3.	V-funnel	8-12 sec	Passing ability
4.	V-funnel-T5min	11-15sec	Segregation resistance
5.	L-Box H2/H1	≥ 0.8	Passing ability

5. MIX PROPORTION OF GFRSCC & TEST RESULTS

5.1 MIX DESIGN CALCULATION

Step 1: Target Mean strength

f'ck = fck + 1.65 × S (S.D from table 1 of IS 10262:2009)

= 25 + 1.65 × 4 = 31.6 N/mm^2

Step 2: Selection of W/C ratio

Maximum w/c ratio for M35 is 1.0 (as per IS 456:2000)

0.9 < 1.0, hence ok.(from graph of IS 10262:1982)

Step 3: Selection of water content

Maximum water content for 12.5mm aggregate – 180 litre (for25-50mm slump from table 2 of IS 10262)

Step 4: Calculation of cement content

w/c ratio = 0.9(from step 3)

Cement content = (2*180)/0.9 = 360 kg/m^3

From table 5 of IS 456, minimum cement content for 'severe'exposure condition=320 kg/m^3

360 kg/m^3 > 320 kg/m^3 , hence ok.

Step 5: Proportion of volume of CA and FA content

From table 3 of IS 10262,Volume of aggregate corresponding to 12.5mm size as per IS 383 and fine aggregate(zone 3) for w/c ratio of 0.9 = 0.6

Volume of Coarse aggregate content=0..6

Volume of Fine aggregate content= 1- 0.60 = 0.40.

Step 6: Mix calculations

Volume of concrete = 1 m^3

Volume of Cement = (Mass of Cement/S.G of cement)×(1/1000)

= (360/3.12)×(1/1000)

= 0.280 m^3

Volume of Water = (Mass of Water/S.G of Water)×(1/1000)

= (180/1)×(1/1000)

= 0.180 m^3

Volume of all in aggregates = 1 – (0.28 +0.18)

= 0.54 m^3

Mass of Fine aggregate = 0.54 × 0.40 × 2.08 × 1000

= 850 kg

Mass of Coarse aggregate = 0.54 × 0.60 × 2.2 × 1000

= 920 kg

After conducting the several trial mixes in the lab, the following mix proportion satisfies all the requirements of SCC in fresh state. The final Mix proportion is shown in Table 5.1 and the workability test results are shown in Table 5.3.

Table 5.1 Mix Proportion of SCC

Designation	Water	Cement	Fly Ash	F.A	C.A	S.P
SCC	180 Kg/m^3	350 Kg/m^3	150 Kg/m^3	850 Kg/m3	920 Kg/m^3	1.00% of cementitious materials

WATER POWDER RATIO IS 0.36 : 1
F.A-Fine Aggregate.
C.A-Coarse Aggregate

S.P-Superplasticizer

About 30% of cement was replaced by Fly Ash.

This SCC mix satisfies all conditions for SCC as per Annex-J in IS456.

Since there is no proper design procedure is available for SCM, the final mix proportions were designed based on the trial and error method in which variousproportions of fly ash and superplasticizer have been tried to arrive at the mix giving the appropriate workability which meets the self compacting standards. The different lengths of fibres (1.2mm, 1.8mm and 2.4mm) were added to the self compacting mix with different percentages (0%, 0.25%, 0.5%, 0.75% and 1%).

Table 5.2 Mix Proportion of GFRSCC

S.NO	Designation	Mix proportion
1	SCC 1	S0.25%G1*
2	SCC 2	S0.50%G1
3	SCC 3	S0.75%G1
4	SCC 4	S1%G1
5	SCC 5	S0.25%G2
6	SCC 6	S0.50%G2
7	SCC 7	S0.75%G2
8	SCC 8	S1%G2
9	SCC 9	S0.25%G3
10	SCC 10	S0.50%G3
11	SCC 11	S0.75%G3
12	SCC 12	S1%G3

S0.25%G1- 0.25% of S-glass fibre content with respect to the binder ratio of lengthG1. (G1-1.2mm; G2-1.8mm; G3-2.4mm)

5.2 WORKABILITY TEST RESULTS FOR GFRSCC

Slump flow, V-funnel and L-box tests were performed in the laboratory on fresh SCC and

GFRSCC to find filling ability, passing ability and segregation resistance. The prescribed limits of the tests as per the EFNARC specifications. The fresh properties of SCC and GFRSCC are shown in Tables 5.3.

Table 5.3 Workability test results for SCC & GFRSCC

S.NO	**Designation**	**Slump flow(mm)**	**T500mm(sec)**	**V-Funnel (sec)**	**V-Funnel at T5min(sec)**	**L-Box (h2/h1)**
1	SCC	720	2	7	9	0.82
2	SCC 1	705	2.5	8	10	0.89
3	SCC 2	695	3	9	11.5	0.93
4	SCC 3	670	4.1	9.5	13	0.99
5	SCC 4	650	5	10	15	1.1
6	SCC 5	701	2.5	7.5	10.5	0.9
7	SCC 6	690	3	8.5	12	0.95
8	SCC 7	665	4	9	13	1.0
9	SCC 8	645	5	10.5	15.5	1.2
10	SCC 9	690	3	8	11	0.91
11	SCC 10	680	4.5	8.9	12.5	0.96
12	SCC 11	660	5	9.6	14	1.1
13	SCC12	635	6	11	16	1.4

T_{50cm}: time taken for concrete to reach the 500 mm spread circle.

T_f: v-funnel flow time after keeping the concrete in funnel for 10 sec. T_{5min}: v-funnel flow time after keeping the concrete in funnel for 5 sec H1, H2: Heights of the concrete at both ends of horizontal section of L-box after allowing the concrete to flow

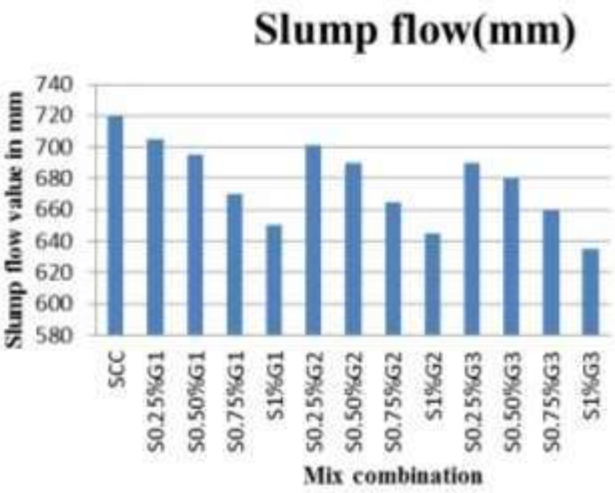


Fig 5.5 Slump Flow Graph

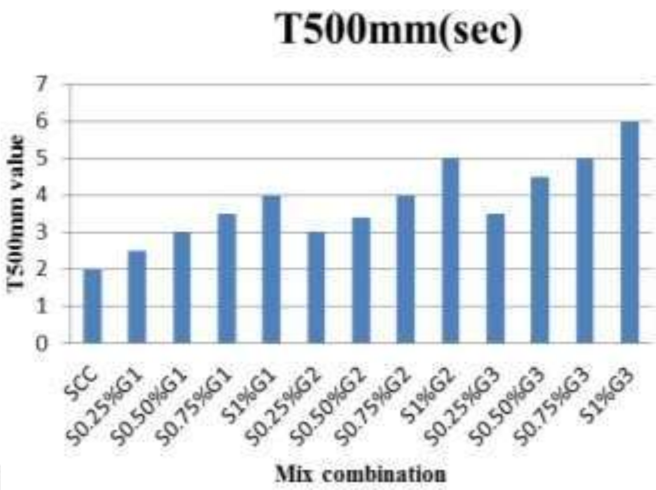
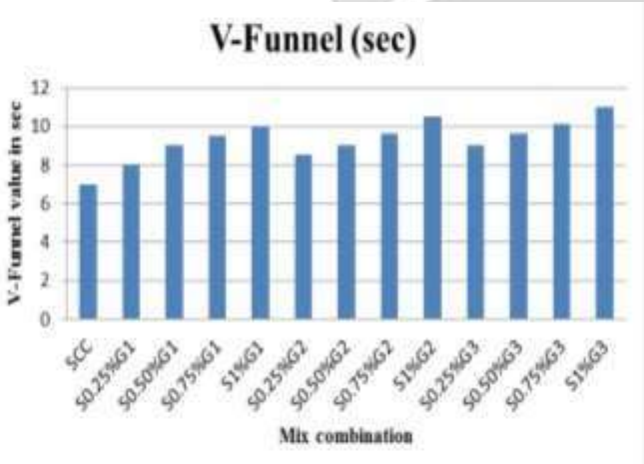


Fig 5.6 T500mm Graph



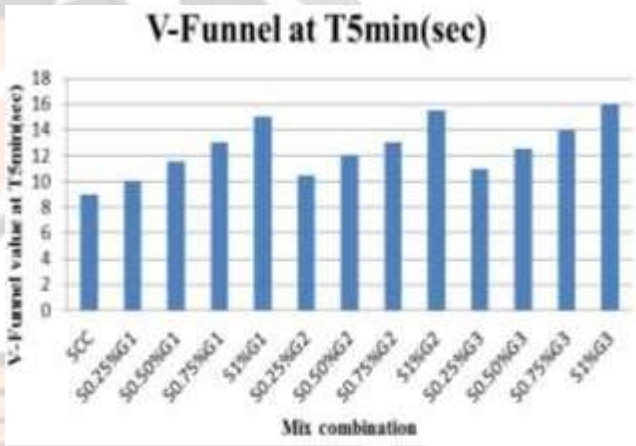


Fig 5.7 V-Funnel Graph

Fig 5.8 T5min Graph

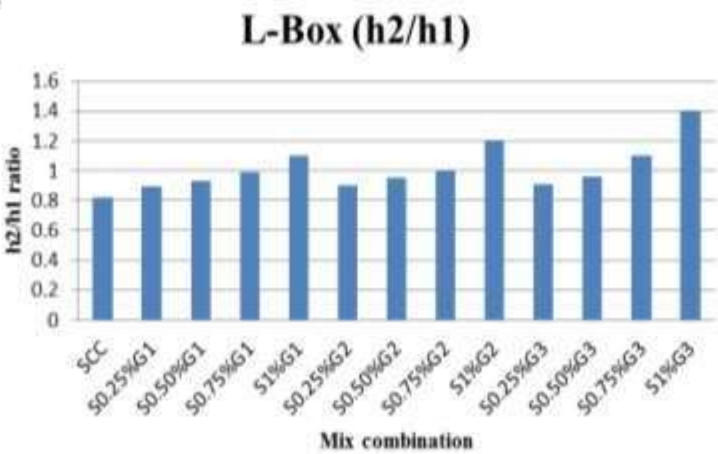


Fig 5.9 L-Box Graph

Table 5.4 Compressive strength results at 7 and 28 days

S.NO	Designation	Compressive strength at 7 days(N/mm^2)	Compressive strength at 28 days(N/mm^2), fck
1	SCC	24	32
2	S0.25%G1	26	32.5
3	S0.50%G1	27	33
4	S0.75%G1	28.5	34
5	S1%G1	30	35
6	S0.25%G2	26.5	33
7	S0.50%G2	28	34
8	S0.75%G2	29	35.5
9	S1%G2	30.5	36
10	S0.25%G3	27	33.5
11	S0.50%G3	28.5	35
12	S0.75%G3	29.5	36
13	S1%G3	31	37

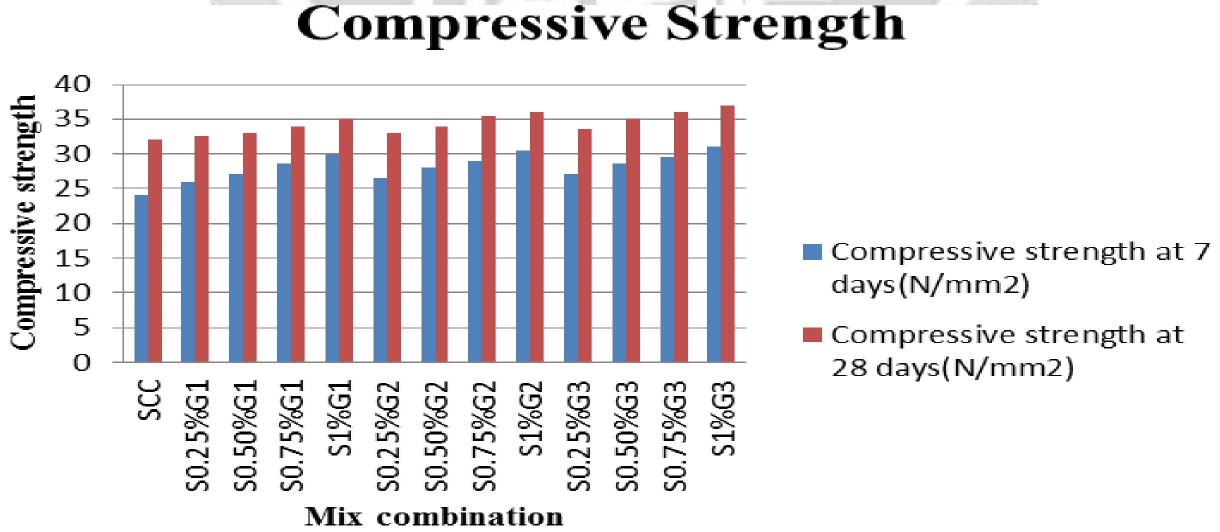


Fig 5.16 Compressive strength at 7 and 28 days

Table 5.5 Flexural strength results at 28 days

S.NO	Designation	Flexural strength at 28 days(N/mm^2)
1	SCC	7.65
2	S0.25%G1	7.95
3	S0.50%G1	8.7
4	S0.75%G1	9.3
5	S1%G1	9.75
6	S0.25%G2	8.175
7	S0.50%G2	8.85
8	S0.75%G2	9.45
9	S1%G2	9.9
10	S0.25%G3	8.55
11	S0.50%G3	8.96
12	S0.75%G3	9.675
13	S1%G3	10.125

Fig 5.18 Flexural strength at 28 days

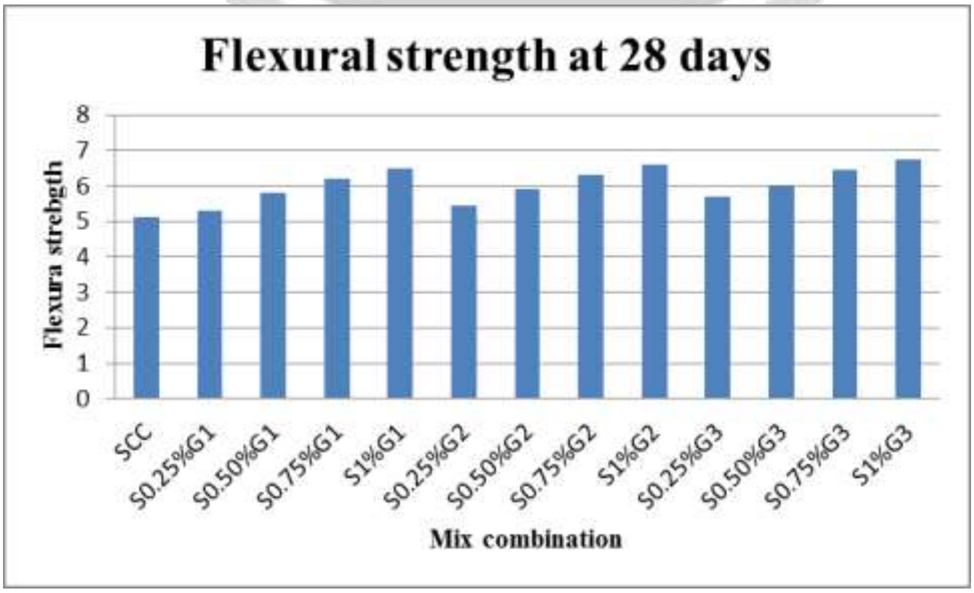
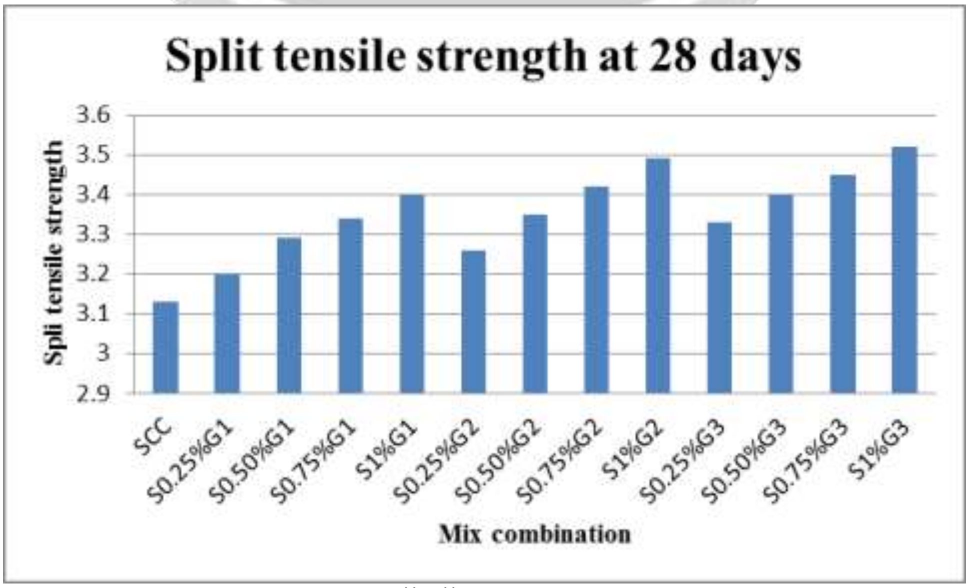


Table 5.6 Split tensile strength at 28 days

S.NO	Designation	Split tensile strength at 28 days(N/mm^2)
1	SCC	3.13
2	S0.25%G1	3.20
3	S0.50%G1	3.29
4	S0.75%G1	3.34
5	S1%G1	3.40
6	S0.25%G2	3.26
7	S0.50%G2	3.35
8	S0.75%G2	3.42
9	S1%G2	3.49
10	S0.25%G3	3.33
11	S0.50%G3	3.40
12	S0.75%G3	3.45
13	S1%G3	3.52

Fig 5.20 Split tensile strength at 28 days



5.3 RESULTS FOR DURABILITY PROPERTIES OF GFRSCC

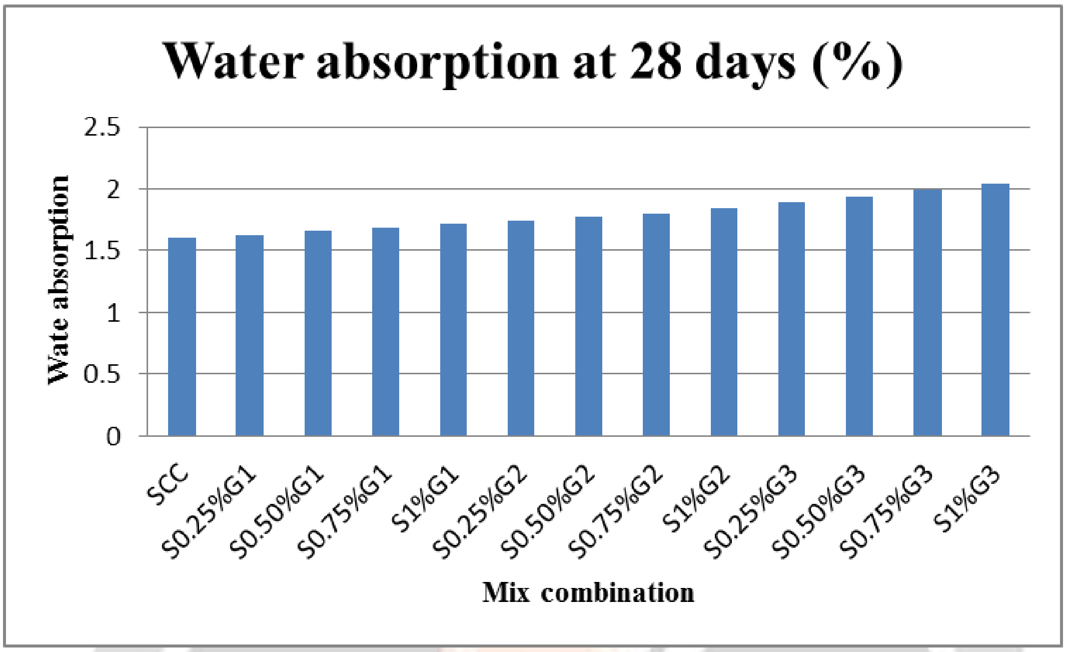
5.6.1 Water Absorption Test

The saturated water absorption test was performed on the cube specimens of size 150 mm after 28 days of curing as per the ASTM C 642-81. From the test results,it is found that at 1% volume of fibres (length of fibre 2.4mm), we get higher water absorption compared to the control concrete and other lengths of fibres.

Table 5.7 Water absorption at 28 days (%)

S.NO	Designation	Water absorption at 28 days (%)
1	SCC	1.6
2	S0.25%G1	1.63
3	S0.50%G1	1.66
4	S0.75%G1	1.68
5	S1%G1	1.72
6	S0.25%G2	1.74
7	S0.50%G2	1.78
8	S0.75%G2	1.80
9	S1%G2	1.85
10	S0.25%G3	1.89
11	S0.50%G3	1.94
12	S0.75%G3	1.99
13	S1%G3	2.04

Fig 5.21 Water absorption at 28 days (%)



5.6.2 Rapid Chloride Penetration Test

The rapid chloride penetration test (RCPT) was performed as per ASTM C 1202 to determine the electrical conductance of the specimens at the age of 28 days curing. From the test results, it is concluded that at 1% volume of fibers (length of fibre 2.4mm), the chloride ion penetration value was decreased compared to thecontrol concrete and other lengths of fibers.

Table 5.8 Chloride penetration value at 28 days

S.NO	Designation	Chloride penetration value at 28 days	Remarks
1	SCC	2500	Moderate
2	S0.25%G1	2400	Moderate
3	S0.50%G1	2250	Moderate
4	S0.75%G1	2100	Moderate
5	S1%G1	2000	Low
6	S0.25%G2	1950	Low
7	S0.50%G2	1870	Low
8	S0.75%G2	1750	Low
9	S1%G2	1590	Low
10	S0.25%G3	1430	Low
11	S0.50%G3	1360	Low
12	S0.75%G3	1280	Low
13	S1%G3	1190	Low

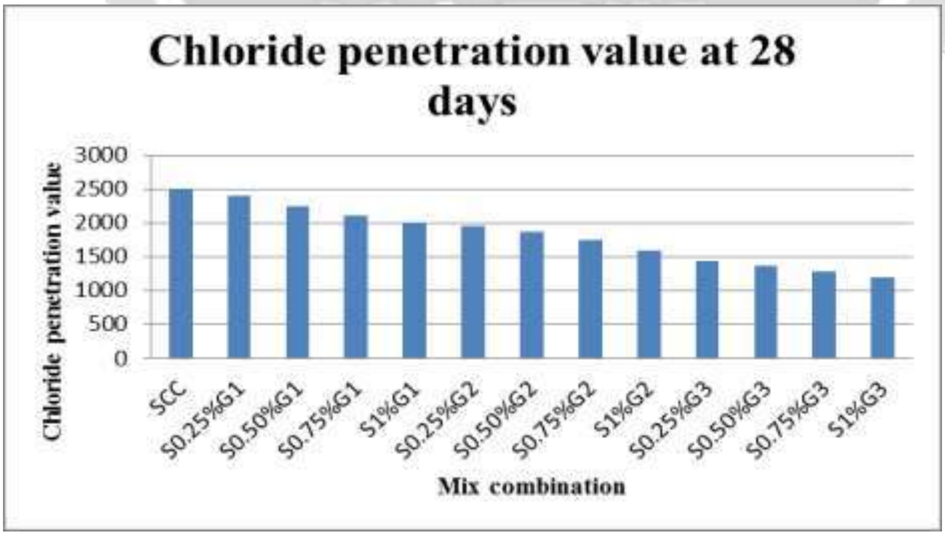
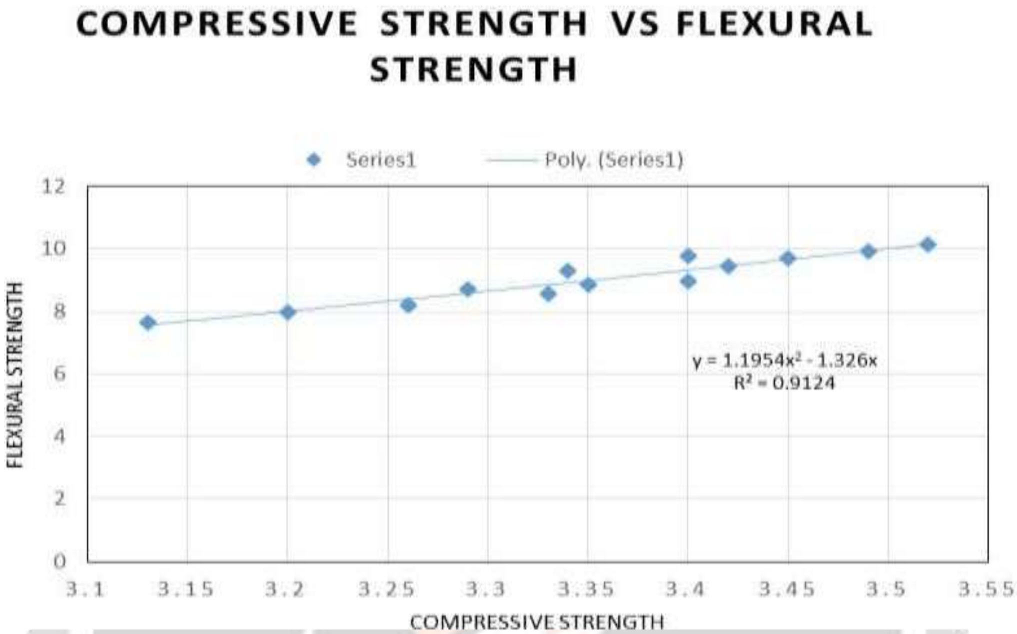


Fig 5.22 Chloride penetration value at 28 days

5.4 COMPARISONS OF TEST RESULTS

The comparison between compressive strength with flexural strength, splittensile strength are shown in Fig 5.23, 5.24



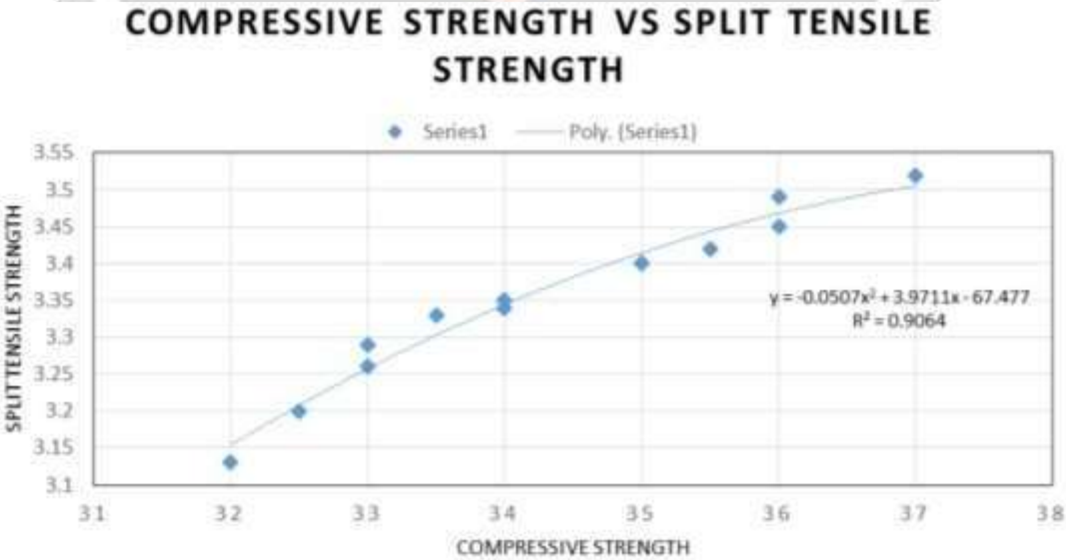


Table 5.9 Modulus of Rupture Factor for Flexural strength

S.NO	Designation	Flexural strength at 28 days(N/mm^2)	Compressive strength at 28 days(N/mm^2), fck	Modulus of rupture factor $x=f_r/(f_{ck})^{1/2}$
1	SCC	7.65	32	1.35
2	S0.25%G1	7.95	32.5	1.39
3	S0.50%G1	8.7	33	1.51
4	S0.75%G1	9.3	34	1.60
5	S1%G1	9.75	35	1.64
6	S0.25%G2	8.175	33	1.42
7	S0.50%G2	8.85	34	1.52
8	S0.75%G2	9.45	35.5	1.58
9	S1%G2	9.9	36	1.65
10	S0.25%G3	8.55	33.5	1.48
11	S0.50%G3	8.96	35	1.51
12	S0.75%G3	9.675	36	1.61
13	S1%G3	10.125	37	1.66

The modulus of rupture factor for flexural strength with repect to square root of fck (charesteristic compressive strength) is found to be in the range 1.25 to 1.75.

Table 5.10 Modulus of Rupture Factor for Split Tensile Strength

S.NO	Designation	Split tensile strength at 28 days(N/mm^2),ft	Compressive strength at 28 days(N/mm^2), fck	Modulus of rupture factor $x1=ft/(fck)^{1/2}$
1	SCC	3.13	32	.55
2	S0.25%G1	3.20	32.5	.56
3	S0.50%G1	3.29	33	.57
4	S0.75%G1	3.34	34	.57
5	S1%G1	3.40	35	.57
6	S0.25%G2	3.26	33	.56
7	S0.50%G2	3.35	34	.57
8	S0.75%G2	3.42	35.5	.57
9	S1%G2	3.49	36	.58
10	S0.25%G3	3.33	33.5	.57
11	S0.50%G3	3.40	35	.57
12	S0.75%G3	3.45	36	.58
13	S1%G3	3.52	37	.57

The modulus of rupture factor for Split tensile strength with repect to square root of fck (charesteristic compressive strength) is found to be in the range 0.5 to 0.6.

6. CONCLUSIONS

In the experimental work, the compressive strength, flexural strength, split tensile strength and durability of SCC and GFRSCC were investigated. Based on the observations made during the various tests conducted on the SCC and GFRSCC specimens and also based on the results obtained from these tests, the salient features are concluded as follows:

1) All the SCC and GFRSCC mixes developed satisfy the requirements of self- compacting concrete specified by EFNARC, up to 1% addition of glass fiber does not affect the fresh concrete properties of SCC.

2) For a given length of S-glass fibre, the compressive strength of GFRSCC increases when the content of the S-glass fibres in the mix increases. For 1.2mm legth fibre 1% addition of glass fibre specimen was found to be 7.1% higher than 0.25% addition of glass fiber. In the same way for 1.8mm glass fiber its 8.3% and for 2.4mm its 9.4%.

3) The maximum percentage increase in compressive strength with respect to the reference SCC mix is 13.5% and it is obtained from the mix containing 1% of S- glass fibres of length 2.4 mm.

4) The flexural strength and splitting tensile strength also shows a similar trend as the compressive strength of the GFRSCC. The maximum percentage of increase in splitting tensile strength with respect to the reference SCC mix is 15% and it is obtained from the mix containing 1% of S-glass fibres of length 24 mm. The maximum percentage of increase in flexural strength with respect to the reference SCC mix is 32% and it is obtained from the mix containing 1% of S-glass fibres of length 24 mm.

5) The total charge passed through the GFRSCC specimens decreases thecontent of S-glass fibres increases in the SCC mix. The lowest total charge passed value of 1190 is obtained for the mix S1%G3 as compared to the maximum total charge passed value of 2500 for the reference mix SCC.

6) The modulus of rupture factor for Flexural strength with repect to the charesteristic compressive strength ranges from 1.25 to 1.75

7 The modulus of rupture factor for Split Tensile strength with repect to thecharesteristic compressive strength ranges from 0.5 to 0.7

8) The Flexural strength can be expressed in the form of a polynomial function of the

ck

characteristic compressive strength. The polynomial equation is $f_r = 1.1954f^{2} - 1.326f_{ck}$.

9) The Split tensile strength can be expressed in the form of a polynomial function of the characteristic compressive strength. The polynomial equation is

$f_t = -0.0507\, f_{ck}^{2} + 3.9711 f_{ck} - 67.477$.

10) In general GFRSCC concrete behavior is better in strength and durability charesteristics than SC.

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