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Strength Characteristics of Glass Fiber Reinforced Self-Compacting Concrete with Fly Ash and Silica Fume

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***Abstract*— Self-compacting concrete (SCC) is a concrete that has a high flowing ability with no segregation. It is considered to be one of the revolutionary developments in concrete technology in recent times. It reduces noise at sites, precast factory and neighborhood. Self-compacting concrete and glass fibers are combined to create glass fiber reinforced self-compacting concrete (GFRSCC). The present work deals with the workability and strength studies on glass fiber reinforced self-compacting concrete of grade M40 with fly ash and silica fume. The mix proportions for self-compacting concrete were arrived at by performing mix design and then fine-tuning using EFNARC guidelines. The cement was replaced by 20% fly ash and 12% silica fume by weight. This was kept constant for all the mixes. The glass fiber percentage was varied from 0 to 0.8 % by weight of concrete. Addition of glass fibers increased the 7 days compressive strength compared to the reference mix (mix with no glass fibers) but the increase was not significant. There was moderate (15% to 21 %) increase in 28 days compressive strength when fibers were added relative to the reference mix. Addition of fibers to self-compacting concrete increased the 7 days splitting tensile strength by 13% to 69%. Addition of fibers to self-compacting concrete increased the 28 days splitting tensile strength by 5% to 50%. Addition of fibers to self-compacting concrete increased the 28 days flexural strength by 30% to 48%. The 7 and 28 days compressive strengths of self-compacting concrete with glass fibers were maximum at a fiber percentage = 0.3. The 7 and 28 days splitting tensile strengths of self-compacting concrete with glass fibers were maximum at a fiber percentage = 0.4. The 28 days flexural strength of self-compacting concrete with glass fibers was maximum at a percentage = 0.7.**

Keywords — Self-compacting concrete ; Glass fibers ; Fly ash ; Silica fume; compressive strength ; splitting tensile strength ; flexural strength.

1. INTRODUCTION

Self-compacting concrete (SCC) fills the formwork with heavily congested reinforcement without any mechanical vibration. It was first developed in 1988 by Professor Okamura in Japan. Self-compacting concrete is considered to be one of the recent revolutionary developments in concrete technology. It reduces noise at sites, precast factory and neighborhood. Fiber reinforced concrete is concrete with discontinuous, discrete, uniformly dispersed suitable fibers. The fiber material can be coir, steel, carbon, polypropylene, glass, nylon and polyester. Glass fiber (also called fiberglass) is a material made from extremely fine fibers of glass. There are several types of glass fibers such as A-glass, E-glass, AE-glass, AR-glass etc. Glass Fiber Reinforced Concrete (GFRC) is made out of conventional concrete reinforced with glass fibers, the quality depending on the glass content, fiber size etc. Self-compacting concrete and glass fibers are combined to create glass fiber reinforced self-compacting concrete (GFRSCC). The present work deals with the strength characteristics of glass fiber reinforced self-compacting concrete. A vast literature exists on self-compacting concrete and glass fibers. A few are mentioned here. P. Srinivasa Rao et al. [1] have studied the strength behavior of fiber reinforced self-compacting concrete of grades M30, M40, M50 and M60 subjected to flexure. The addition of fibers was observed to have no influence on the flexural strength. However, addition of glass fibers was observed to prevent development of multiple cracks and micro cracks. T. Suresh Babu et al. [2] have studied the mechanical properties and stress-strain behavior of self-compacting concrete and glass fiber reinforced self-compacting concrete. The empirical equations proposed in this work depict the complete stress-strain behavior of self-compacting concrete and glass fiber reinforced self-compacting concrete mixes under compression. The equations are valid for M30 grade concrete. P. Bhuvaneshwari and R. Murali [3] have studied the effects of replacing fine aggregate in concrete mix with bottom ash and adding glass fibers on the strength characteristics of concrete. There was no reduction in strength for beams with bottom ash as replacement for fine aggregate. The addition of fibers reduced the workability of concrete and this was overcome by the addition of bottom ash replacement of fine aggregate.

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Chandramouli K and Srinivasa Rao [4] have studied the effect of alkali resistant glass fibers on the compressive, splitting tensile and flexural strengths of M20, M30, M40 and M50 grades of concrete. A reduction in bleeding was observed due to the addition of glass fibers in the concrete mixes. The percentage increase of compressive strength of glass fiber concrete mixes was observed to be in the range of 20% to 25%. The percentage increase of flexural and splitting tensile strengths was observed to be in the range of 15% to 20%. K. Rajesh Kumar and N. Mahendran [5] have studied the mechanical properties, durability and structural behavior of beams with E-glass fiber chopped strands self-compacting concrete with partial replacement of cement by fly ash. The addition of glass fiber strands improved the compressive strength, tensile strength, durability and load carrying capacity of ordinary reinforced cement concrete in flexure even with small dosage levels of 0.03% and 0.06%. Rama Mohan Rao P et al. [6] found that the glass fibers slightly improved the 28 days compressive strength of flyash concrete. There was an increase from 8.5% to 16% in the splitting tensile strength for all mixes compared to that of control mix. Parviz Soroushian [7] studied about the effectiveness of various types of steel fibers in concrete. It was observed that the addition of fibers decreased the workability, more in the case of fibers with higher aspect ratios. Crimped fibers were found to be better when compared to straight and hooked fibers. Yogesh Murthy et al. [8] found that the use of glass fibers improved the properties of concrete. The flexural strength of the beam with 1.5% glass fiber showed almost 30% increase in the strength. Avinash Gornale et al. [9] found that the increases in compressive, flexural and splitting tensile strengths of conventional concrete with glass fibers at 3, 7 and 28 days were 20% to 30%, 25% to 30% and 25% to 30% respectively as compared to the concrete without fibers. Annie Peter J et al.[10] studied the structural behavior of self-compacting concrete and conventionally vibrated concrete. Both exhibited similar strengths at ages of 1, 3, 7 and 28 days. While the peak and failure loads were almost the same for conventionally vibrated concrete beams, the failure load was nearly 25 % lower compared to the peak load in self-compacting concrete beams. Ganeshan N et al. [11] studied the effect of steel fibers on the strength and behavior of self-compacting concrete flexural elements. First crack load and the post-cracking behavior were found to have improved significantly due to the addition of fibers. A marginal improvement in the ultimate strength was observed. The addition of fibers enhanced the ductility significantly. The optimum volume fraction of fibers for better performance in terms of strength and ductility was found to be 0.5 percent. Liaqat A. Qureshi [12] has studied the effect of using glass fibers on the strength properties of concrete. The results showed that workability of glass fiber reinforced concrete decreased by increasing glass fiber content. In such cases some water reducing admixtures may be suggested to get the required workability of concrete without compromising on strength.

2. PRESENT WORK

2.1 Scope

The scope of the present work is limited to workability and strength studies on glass fiber reinforced self-compacting concrete with fly ash and silica fume of grade M40.

2.2 Materials Used

The cement used in the present work was 53 grade Portland cement. The properties of cement which were experimentally determined in the present work are given in Table 1.

Table 1: Physical Properties of Cement Used

Sl. No.	Property		Value	Requirement as per IS:12269-1987
1	Standard consistency		27%	28%
2	Fineness (retained on 90µ sieve)		3%	≤ 10%
3	Soundness (Le Chatelier)		3 mm	≤ 10 mm
4	Initial setting time (minutes)		62	≥ 30 minutes
5	Final setting time (minutes)		370	≤ 600 minutes
6	Specific gravity		2.95	-------
7	Compressive strength	7 days	45	≥ 37 N/mm^2
		28 days	65	≥ 53 N/mm^2

The properties of the coarse aggregate used in the present work are given in Table 2.

Table 2: Physical Properties of Coarse Aggregate

Sl No.	Property	Value
1	Surface Texture	Crystalline
2	Particle Shape	Angular
3	Specific gravity	2.69
4	Water absorption	0.24%
5	Bulk density	1.62

Manufactured sand from nearby crusher was used in the present work. The physical properties of fine aggregate used were determined in accordance with IS:2386 -1963 and the same are given in Table 3.

Table 3: Physical Properties of Fine Aggregate

Sl. No.	Property	Value
1	Type	Manufactured
2	Surface texture	Crystalline
3	Specify gravity	2.62
4	Water absorption	3.8%
5	Moisture content	0.8%
6	Fineness modulus	2.68
7	Grading zone	Zone II

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Fly ash used in the present work was obtained from Kudathini, Bellary (District) Thermal Power Station, Karnataka. The specific gravity of the fly ash used was 2.08. The chemical composition of fly ash is given in Table 4.

Table 4: Chemical Composition of Fly Ash

Sl. No.	Ingredient	Quantity (% wt)
1	Silicon Dioxide (SiO_2)	62.63
2	Alumina (Al_2O_3)	23.35
3	Iron oxide(Fe_2O_3)	3.93
4	Calcium oxide (CaO)	2.04
5	Magnesium oxide (MgO)	0.46
6	Sulfur tri oxide (SO_3)	1.34
7	Sodium oxide (Na_2O)	0.032
8	Potassium oxide (K_2O)	0.030
9	Loss on ignition % by mass	0.39
10	Bulk density	1.11gm/cc

The silica fume used in the present work was obtained from Corniche India Pvt. Ltd. Mumbai. Specific gravity was 2.15. Table 5 shows the chemical composition of silica fume used.

Table 5: Chemical Composition of Silica Fume

Sl. No.	Ingredient	Value	Requirements as per ASTM-C-1240
1	SiO_2	91.9%	Min. 85%
2	Loss on Ignition	2.8%	Max. 6%
3	Moisture	0.3 %	Max. 3%
4	Pozzolonic Activity Index	133%	Min. 105%
5	Specific Surface Area	22 m^2/gm	Min. 15 m^2/gm
6	Bulk Density	601	550-700

AUROMIX 400, a super plasticizer manufactured by FOSROC constructive solutions, was used in the present work. The properties provided by the supplier are listed in Table 6.

Table 6: Typical Properties of AUROMIX 400 Super Plasticizer

PROPERTY	VALUE
Appearance	Light yellow colored liquid
PH	Min 6
Volumetric mass@200°c	1.09kg per liter
Chloride content	Nil
Alkali content	<1.5g Na2o proportionate liter of admixture

Potable water was used for mixing and curing. The glass fibers used were of round cross-section and had an aspect ratio of 875. The length was 12 mm. The diameter was 0.014 mm. These were procured from a supplier at Gujarat. The properties furnished by the supplier are given Table 7.

Table 7: Properties of Glass Fibers

Property	Value
Appearance	white
Density (g/cm^3)	0.91
Fire reaction	incombustible
Tensile strength	> 600 MPa
Elastic modulus	> 3500 MPa
Crack elongation (%)	10 minimum
Melting point	12000°C
Heat conduction	low

2.3 Mix Proportions Used

The mix proportions for self-compacting concrete were arrived at by performing mix design and fine-tuning using EFNARC guidelines. The cement was replaced by 20% fly ash and 12% silica fume by weight. This was kept constant for all the mixes. The glass fiber percentage was varied from 0 to 0.8 percent by weight of concrete. The details of the various mixes used in the present work are given in Table 8.

2.4 Flow tests

For each mix, tests were conducted to assess workability properties of concrete (such as slump flow, V-funnel test, L-box test and U-box test). The results are given in Table 9.

Comparison of Table 9 with EFNARC guidelines shows that all the mixes satisfy the workability requirements of self-compacting concrete. It is also seen that the flow properties decrease as the fiber percentage increases.

2.5 Compressive Strength Tests

Fresh concrete was filled into cubes without any compaction. The top surface was finished with a trowel and left for 24 hours for setting of concrete. The cubes were tested in 3000 kN capacity compression testing machine loaded at 140 kg/cm^2/minute as per standard procedure explained in IS: 516-1956 (1999) to get the compressive strength of the concrete at 7 and 28 days. The results are given in Table 10 and plotted in Fig.1. The number within parentheses in Table 10 represents the percentage of increase in strength relative to reference mix. From Table 10 and Fig.1, the following observations are made:

- The variation of 7 days compressive strength of self-compacting concrete with glass fiber percentage is not significant. Addition of glass fibers does increase the strength compared to the reference mix but the increase is not significant.
- The variation of 28 days compressive strength of self-compacting concrete with glass fiber percentage is not significant. However, there is moderate (15% to 21 %) increase in strength when fibers are added compared to the reference mix.
- The 7 and 28 days compressive strengths of self-compacting concrete with glass fibers are maximum at a fiber percentage = 0.3.

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Table 8: Mix Proportions Used

Mix Designation	Cement Kg/m^3	Fly Ash Kg/m^3	Silica Fume Kg/m^3	FA Kg/m^3	CA Kg/m^3	W/C Ratio	SP Kg/m^3	Glass Fibers %
Ref. Mix	380.33	77.73	48.91	883.09	714.42	0.498	4.05	0.0
Mix 1	380.33	77.73	48.91	883.09	714.42	0.498	4.05	0.1
Mix 2	380.33	77.73	48.91	883.09	714.42	0.498	4.05	0.2
Mix 3	380.33	77.73	48.91	883.09	714.42	0.498	4.05	0.3
Mix 4	380.33	77.73	48.91	883.09	714.42	0.498	4.05	0.4
Mix 5	380.33	77.73	48.91	883.09	714.42	0.498	4.05	0.5
Mix 6	380.33	77.73	48.91	883.09	714.42	0.498	4.05	0.6
Mix 7	380.33	77.73	48.91	883.09	714.42	0.498	4.05	0.7
Mix 8	380.33	77.73	48.91	883.09	714.42	0.498	4.05	0.8

Table 9: Results of Flow Tests on SCC with Glass Fibers

Mix designation	% of Glass Fibers	Slump Flow Test *Dia.(mm)*	T-50 cm Test (seconds)	V-funnel Test (seconds)	U-Box Test H_2-H_1 *(mm)*	J-Ring Test H_2-H_1 *(mm)*	L-Box Test H_2-H_1 *(mm)*
Ref. Mix	0.0%	705	5	12	9	9	0.90
Mix 1	0.1%	700	5	12	9	9	0.90
Mix 2	0.2%	695	5	12	9	8	0.89
Mix 3	0.3%	689	4	11	8	7	0.80
Mix 4	0.4%	687	4	11	8	7	0.75
Mix 5	0.5%	681	4	11	8	6	0.72
Mix 6	0.6%	680	3	10	7	5	0.65
Mix 7	0.7%	678	2	8	6	4	0.60
Mix 8	0.8%	675	2	7	6	4	0.60

Table 10: Compression Test Results of SCC with Glass Fibers

Mix	Compressive Strength (N/mm^2)	
	7 days	28 days
Ref. Mix	30.13	40.62
Mix 1	31.62 (4.94%)	48.90 (20.30%)
Mix 2	32.89 (9.16%)	48.74 (19.99%)
Mix 3	33.53(11.28%)	49.31 (21.39%)
Mix 4	33.20 (10.18%) (((10.18%)(10.18%	49.00 (20.63%)
Mix 5	33.31 (10.55%)	48.70 (19.89%)
Mix 6	31.29 (3.84%)	48.26 (18.80%)
Mix 7	31.00 (2.92%)	47.10 (15.95%)
Mix 8	30.22 (0.30%)	47.00 (15.0%)

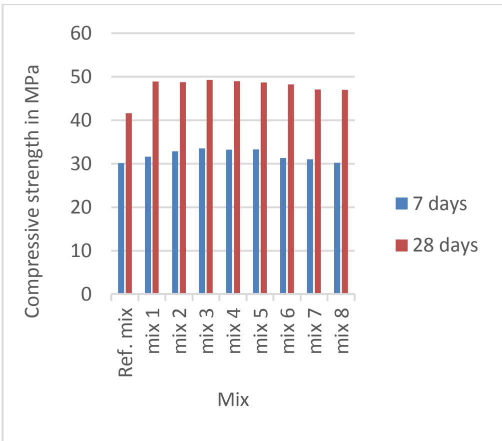

Fig.1: 7 and 28 Days Compressive Strength of SCC With and Without Glass Fibers

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2.6 Splitting Tensile Strength Tests

Fresh concrete is filled into cylinders without any compaction. The top surface is finished with a trowel and left for 24 hours for setting of concrete. The test is conducted as per IS: 5816-1999. A concrete cylinder of size 150 mm diameter × 300 mm height is subjected to the action of axial compression at a rate of 4 tonnes / minutes.

Fig. 2: Split tensile test set up

The results are given in Table 11 and plotted in Fig.3.

Table 11: Splitting Tensile Strength Results of SCC With and Without Glass Fibers

Mix	Splitting Tensile Strength (N/mm^2)	
	7 days	28 days
Ref. Mix	3.10	4.10
Mix 1	3.50 (12.9%)	4.57 (11.19%)
Mix 2	4.10 (32.26%)	4.72 (14.84%)
Mix 3	4.40 (41.93%)	5.80 (41.11%)
Mix 4	5.25 (69.35%)	6.15 (49.63%)
Mix 5	4.79 (54.51%)	5.90 (43.55%)
Mix 6	4.10 (32.26%)	5.20 (26.52%)
Mix 7	4.36 (40.64%)	4.89 (18.97%)
Mix 8	3.80 (22.58%)	4.31 (4.86%)

The number within parentheses in Table 11 represents the percentage of increase in strength relative to reference mix.

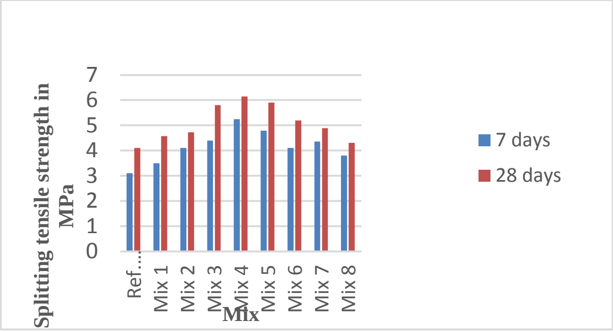

Fig.3: 7 and 28 Days Splitting Tensile Strength of SCC With and Without Glass Fibers

From Table 11 and Fig.3, the following observations are made:

- The variation of 7 days splitting tensile strength of self-compacting concrete with glass fiber percentage is moderate.
- The variation of 28 days splitting tensile strength of self-compacting concrete with glass fiber percentage is moderate.
- The 7 and 28 days splitting tensile strengths of self-compacting concrete with glass fibers are maximum at a fiber percentage = 0.4.
- Addition of fibers to self-compacting concrete increases the 7 days splitting tensile strength by 13% to 69%. Addition of fibers to self-compacting concrete increases the 28 days splitting tensile strength by 5% to 50%.

2.7 Flexural Strength Tests

Fresh concrete is filled into prisms without any compaction. The top surface is finished with a trowel and left for 24 hours for setting of concrete. Flexure tests are carried out on beams of dimensions 500 mm × 100 mm × 100 mm under two point loading in universal testing machine as per BIS specifications and procedures.

Fig. 4: Flexure Test Set Up

The results are given in Table 12 and plotted in Fig.5.

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Table 12: Flexural Strength Results of SCC with glass fibers

Mix	28 days flexural strength (MPa)
Ref. Mix	9.10
Mix 1	11.8 (29.67%)
Mix 2	12.0 (31.86%)
Mix 3	12.3 (35.16%)
Mix 4	12.7 (39.56%)
Mix 5	12.9 (41.79%)
Mix 6	13.1 (43.95%)
Mix 7	13.5 (48.35%)
Mix 8	13.2 (45.05%)

The number within parentheses in Table 12 represents the percentage of increase in strength relative to reference mix.

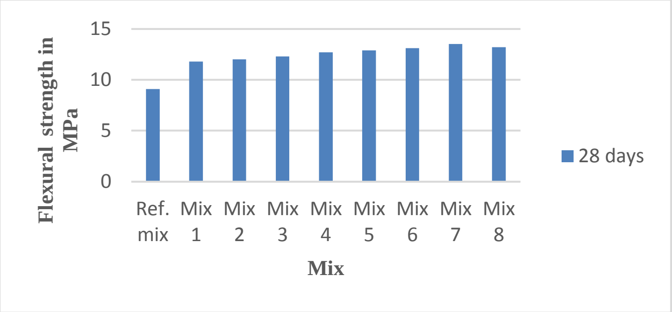

Fig.5: 28 days flexural strength of SCC with and without glass fibers

From Table 12 and Fig.5, the following observations are made:

- The variation of 28 days flexural strength of self-compacting concrete with glass fiber percentage is small.
- The 28 days flexural strength of self-compacting concrete with glass fibers is maximum at a percentage = 0.7.
- Addition of fibers to self-compacting concrete increases the 28 days flexural strength by 30% to 48%.

3. CONCLUSIONS

Based on the present work the following conclusions are drawn:

- The variations of 7 days and 28 days compressive strengths of self-compacting concrete with glass fiber percentage are not significant. The variations of 7 days and 28 days splitting tensile strengths of self-compacting concrete with glass fiber percentage are moderate. The variation of 28 days flexural strength of self-compacting concrete with glass fiber percentage is small.
- Addition of glass fibers increases the 7 days compressive strength compared to the reference mix but the increase is not significant. There is moderate (15% to 21 %) increase in 28 days compressive strength when fibers are added compared to the reference mix. Addition of fibers to self-compacting concrete increases the 7 days splitting tensile strength by 13% to 69%. Addition of fibers to self-compacting concrete increases the 28 days splitting tensile strength by 5% to 50%. Addition of fibers to self-compacting concrete increases the 28 days flexural strength by 30% to 48%.
- The 7 and 28 days compressive strengths of self-compacting concrete with glass fibers are maximum at a fiber percentage = 0.3. The 7 and 28 days splitting tensile strengths of self-compacting concrete with glass fibers are maximum at a fiber percentage = 0.4. The 28 days flexural strength of self-compacting concrete with glass fibers is maximum at a percentage = 0.7.

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