Investigation on Strength Characteristics of Self Compacting Concrete incorporated with AR Glass Fibers

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Abstract. This project presents the experimental study on self-compacting concrete (SCC) with replacement of cement by various percentage of Silica Fume and Fly Ash. The main objective is to determine the Flexural strength, Compressive strength and Split tensile strength of Self compacting concrete by partial replacement of cement by Silica Fume and Fly Ash. The use of fly ash in concrete today is an important subject and is of growing importance day by day. Using fly ash in concrete many provide both economic advantages and enhanced properties in the production of concrete. The addition of super plasticizer increases the workability of concrete. The work involves making seven types of SCCs mixes. For each mix preparation, twenty-one cube specimens, twenty-one-cylinder specimens and twenty-one beam specimens are cast and cured. The specimens are cured in water for 7 days, 14 days and 21 days. The results show that SCC with 5 % SF and 10 % gives higher values of Compressive strength, Split Tensile strength and Flexural Strength compared to other percentages of Silica Fume and Fly Ash. According to the SCC result, various percentages of AR Glass Fiber (0.1 % to 0.4 %) added with the optimum SCC (5% of SF+ 10% of FA) and super plasticizer is mixed with optimum SCC. After each mix proportion, specimens are cast and cured for 28 days in water and hardened properties are determined. The results show that the higher the percentage of glass fiber, the higher the values of concrete Compressive strength, Split Tensile Strength and Flexural Strength.

1 Introduction

Since the 1980s, self-compacting concrete (SCC) has been widely used in Japan's building sector. [1] At the same time, SCC has its weight without compaction by using an external vibrator and low air content. [2] Due to its high viscosity, which prevents segregation and bleeding, SCC is also known as a specific form of concrete. [3] Compared to conventional concrete, SCC has several advantages, including reducing skilled labor expenses, consuming

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construction time, and vibrating equipment costs. [4] [5] In regular concrete, one of the essential factors is compaction which is critical to maintaining uniformity and mechanical stability. Inadequate compaction leads to honeycomb and trapped air, which causes problems with penetration, corrosion of the steel, and a drop in the ultimate bearing capacity of the hardened concrete**.** [4][6] SCC resolves the compaction issues by consolidating itself. Greenhouse gases are emitted in large quantities due to cement consumption in concrete. [7] In order to promote sustainable growth and waste disposal, industrial waste products like fly ash and silica fume are used as a substitute for cement to create SCC. Their properties are like cementitious materials. Thermal power plants release the waste as fly ash for coal production. Flyash is a pozzolanic material that is high in silica content. [8] Nowadays, fly ash is rapidly increasing in the construction industry for making concrete and bricks. Fly ash application improves the workability, flow capacity, and mechanical properties of SCC. Furthermore, it prevents segregation and bleeding of concrete mix. [6] reported that strength properties could be improved by 30% FA by replacing cement with steel fiber. [2] used 15% of SF with SP giving the result as the highest compressive strength of concrete. Adding 15% SF enhances the strength properties, and 30% of FA gives higher compressive strength after curing for 28 days (about 4 weeks) [4]. [6] Conversely, Electric arc furnaces used in Ferrosilicon or Silicon metal manufacture release Silica Fume as a by-product. [9] Concrete can be made with good amorphous silica particles as small as one micron in diameter using silica fume or micro-silica as a supplementary material. [10] Concrete can be made with good amorphous silica particles as small as one micron in diameter using silica fume or micro-silica as a supplementary material. [11] studied the fractal characteristics of pores structures in SCC by using SF. [9] found that using 7% and 14 % of SF as a partial replacement of cement in SCC enhances the spécimens mechanical properties and impact resistance. [1]The modulus of elasticity of SCC increased as the content of Silica fume increased. [12] The concrete is reinforced with fiber and has more advantages, like increasing the concrete's durability, tensile strength, and impact strength. Fibre is incorporated with SCC and has several benefits in heavily reinforced areas.[13] investigated the properties of SCC with glass fibre were enhanced compared to steel fiber. [14] It was discovered that the addition of glass to SCC has more remarkable mechanical properties than Polyvinyl Alcohol fibre. This study examines the hardened characteristics of self-compacting concrete that includes different amounts of fly ash and silica fume in place of cement. The optimum mix proportion of SCC is added with various rates of AR glass fiber (FRSCC). FRSCC is to investigate the new concrete test as slump cone test, V-funnel test, L- box test, and J-Ring test and find the hardened test on FRSCC is compressive strength, Tensile strength, and flexural strength.

2 EXPERIMENTAL PROCEDURE

2.1 Materials

The Ordinary Portland Cement (OPC) grade A 53 was employed in this investigation, which adhered to IS IS8112:1987. The specific gravity of cement as 3.1and the fineness modulus is 4 %.Sand was determined to have a specific gravity of 2.2 and be Zone I sand. The utilised coarse aggregates' dry density was discovered to be 2.58. Fine aggregates had a size of 0.125 mm (about 0 in), whereas coarse aggregates had a size of 20 mm (about 0.79 in). Class F FA meeting ASTM C 618 - 15 criteria with specific gravity of 2.13 and fineness of 114.30 m^2/kg.

Table 1 reveals the chemical composition of Flyash. The fumes typically contain a minimum of 85% silicon dioxide, most of it amorphous, according to ASTM C1240. Carbon, sulphur, and the oxides of aluminium, iron, calcium, magnesium, sodium, and potassium are other components. Silica fume has a specific gravity of 2.13, a fineness of 14920 m2/kg, and an L.O.I. of 3.5% (as per code 6%). The concrete specimen is mixed and cured using regular drinking water, typically with a pH of 7. Because SP 430 is a crucial part of SCC and provides the requisite workability, it is used. The chemical constitution of the fly ash in Table 1.)[15] Alkali-resistant glass fibers (AR glass) containing ZrO2 became commercially available in the early 1980s and were employed as reinforcing cement and concrete products. Before the melting process, Zirconium is added to the glass during the melting process. [13] As a result, rather than being an applied coating, it is an integral part of the composite. The optimal amount of Zirconium has been determined to be between 12 and 20 percent. [16] (AR-glass) was developed due to continued research, which enhanced long-term durability, although other sources of strength-loss trends were discovered. Fiber embrittlement caused by calcium hydroxide particles into fiber bundles, a consequence of cement hydration, was identified as one source. The two following widely accepted theories are based on cement hydration and alkali reactivity and explain strength and ductility loss, particularly in exterior glass fibre concrete. The chemical composition of AR Glass fibre is shown in the Table 2.

Table 1: Chemical Composition of Flyash

Oxides	Percentages
SiO_2	59.09
Al_2O_3	27.9
Fe_2O_3	7.09
MgO	0.98
K_2O	1.98
SO_3	0.66
LOI	2.67

Table 2: Chemical Composition AR Glass Fiber

Component	**Quality Range**
Silica	60-70%
Alumina	0-5%
Zirconium	12-20%
Lime	0-10%
Titanium	0-5%

2.2 Methodology

The main objective of this experiment is to substitute cement with varied amounts of fly ash and silica fume. Seven different SCC mixes are created as part of the work. Twenty-one cube specimens, twenty-one-cylinder specimens, and twenty-one beam specimens are cast and cured for each mix production. The samples are cured in water for 7, 14, and 28 days (about 4 weeks). Both fresh concrete and hardened concrete are subjected to tests. On the brand-new SCC, tests such as the slump cone, U-Box, L-Box, J-Ring, and V-funnel are conducted. Compressive strength, split tensile strength, and flexural strength of hardened concrete are measured. Optimum SCC was found from the result. Added the various percentages of (0.1% to 0.4%) AR Glass fibers with optimum SCC. Long-term durability may be enhanced by the addition of Alkali Resistant Glass Fiber (AR Glass Fiber).

2.3 Mix Design

SCC is making seven mixes that were developed. In the experiment, a mixed ratio of 1:1.86:1.67 was used, with a water/binder ratio of 0.45. Table 3 & 4 provides an illustration of the effects of fly ash and silica fumes on the characteristics of freshly constructed concrete. The necessary amount of water was added to this dry mixture and well-combined. The superplasticizer was then thoroughly mixed into this mixture at a rate of 1.5 lit/m^3 of cementitious material. For the optimal SCC mix to contain AR Glass Fiber, the mixing process is repeated. The mixture was supplemented with various amounts of glass fibre (0.1%, 0.2%, 0.3%, and 0.4%). Without compacting, the entire mixture was properly combined before being put into the moulds. The specimens are formed and cured after casting. The specimens were examined for their individual strengths after 28 days (about 4 weeks) of curing, and the ideal value of SCC+AR Glass Fiber was discovered.

Table 3 Mix Proportions

Constituents	**Contents**
Cement content	500 kg/m^3
Water content	229 kg/m^3
Coarse aggregate	800 kg/m^3
Fine aggregate	930 kg/m3

3. Results and Discussions

3.1 Test on Fresh Concrete

The qualities of fresh concrete were evaluated using different percentages of ARGF utilizing the slump test test, the V funnel test, the L box test, and the J Ring test in accordance with the EFNARC specification (A.R. glass fiber) in Table 6. Table 5 it was revealed that the slump flow test for all mixes had varying percentages of fly ash and silica fume. They discovered the optimum percentage of SCC to be combined with various percentages of ARGF. Deformability, good stability, and a low chance of obstruction are indeed the basic workability requirements for effective SCC casting. [17] According to the EFNARC specification, regarding slump flow, all SCCs give consistent results in the 550–800 mm range and show excellent deformability. Fig 1 showed that SCC 6 has highest slump value as 730 mm. To look at it another way, all the mixes were sufficiently deformable under their own pressure and had a mild viscosity, both of which were required to avoid segregation. [13] Fibers with pinned ends cause particle blocking during movement; the strength of this impact, of course, is relative to the amount of fiber in the mixture. [14] revealed that incorporating the glass fiber and PVA fibers into SCC gradually reduces the slump value compared to without fibers in SCC. [9] discovered that adding 14 % silica fume and 0.75 % steel fiber to SCC results in a 15% reduction when compared to the control mixture of SCC. In this investigation, adding 0.1 to 0.4% of glass fiber to the ideal blend SCC resulted in a slump flow value between 660 and 710 mm. in Fig 2. This value meets the requirements of the ENFARC guidelines. Apart from the fiber's surface area, which demands more mortar to surround it, this decrease is due to an increase in mixed viscosity. In the ENFARC guidelines, the L-box test should be a blocking ratio where the minimum value is 0.8, and the maximum value is 1. [7] found that the L box value lies between 0.8 and 1. [2] This test evaluates the ease with which concrete flows and navigates reinforcing obstructions. The present study revealed that the blocking ratio of all the cast is between 0.7 to 0.9. Fig 3 The test result satisfies the target value 1. Hence it is recommended the SCC. In a V-funnel test, all SCCs possess flow times between 6 and 12 seconds as per ENFARC specification shown in Fig 4. [5] V funnel are to calculate the concrete's capacity for flow. When correlating the M-sand to river sand, the flow time is greater. [6] Slump flow and v-funnels tests for all SCC mixes to meet the requirements of ENFARC. The result found that all mixes were in the range of flow times of 7 to 12 s, apart from adding the 4% of ARGF. The J ring test resulted in a range of 6 to 22 mm, revealed in Fig 5. By adding 0.33% and 0.40% of ARGF, the values are 15 and 22mm. As per EFNARC guidelines, the maximum value of the J ring test is 10 mm for SCC. Experimental results showed that empirical correlations might be used to relate the fiber added to the properties of the fiber-reinforced SCC specimens in their fresh state and their hardened state. Regression analysis produced equations with a high coefficient of determination (R^2). Fig 7 illustrates the empirical correlation between the fresh state features of SCC and the ARGF fraction. According to the relationships, the reinforced SCC mixes' ARGF content can be connected linearly to Slump flow diameter, L-box blocking ratio, V-Funnel, and J-ring step height are all variables to consider. All the fresh state parameters were found to have a strong relationship with a high coefficient of determination.

Table 5 Slump Test on SCC Trial Mix

S. No	Identification	Silica Fume(%)	Fly Ash (%)	Slump Flow(mm)
1	SCC 1(PPC)	15	10	650
2	SCC 2(OPC)	15	10	660
3	SCC 3(OPC)	10	15	680
4	SCC 4(OPC)	10	10	670
5	SCC 5(OPC)	10	20	680
6	SCC 6(OPC)	5	10	730
7	SCC 7(OPC)	5	15	660

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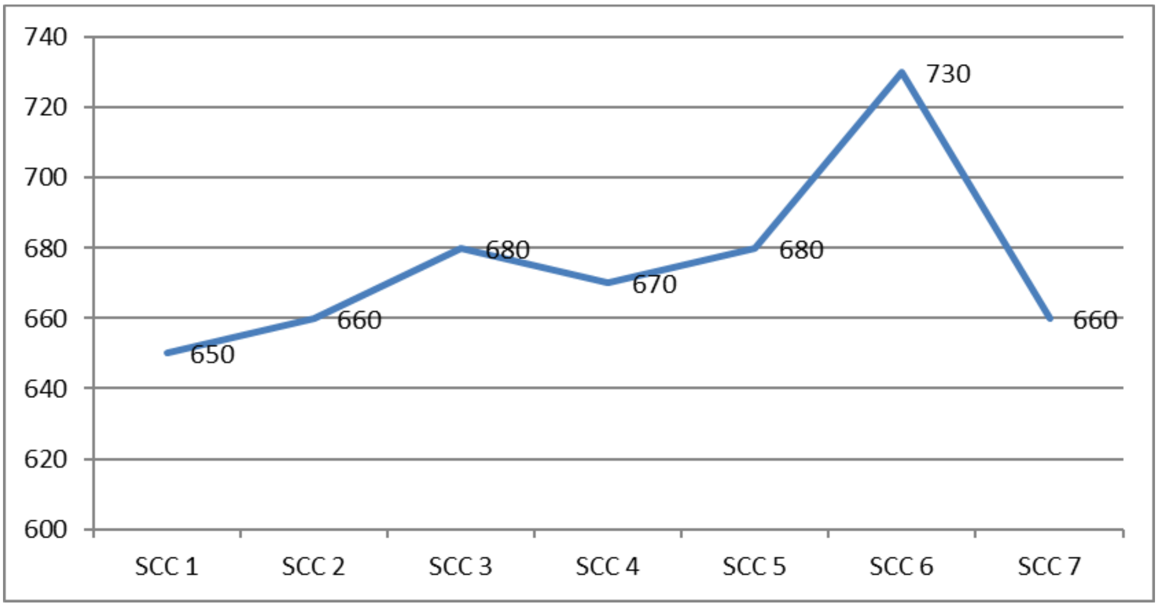

Fig 1 Slump Test on SCC Trial Mix

Table 6 Properties Of Fresh Concrete

S. No	Percentage of AR Glass fibre	Properties related to SCC 6				
		Slump flow (mm)	**L-Box H2/h1**	**U-Box (H2-h1)**	**V-Funnel (sec)**	**J-Ring (mm)**
1	0.1	660	0.96	10	7	6
2	0.2	650	0.98	26	9	9
3	0.3	680	0.87	35	12	15
4	0.4	710	0.76	55	17	22

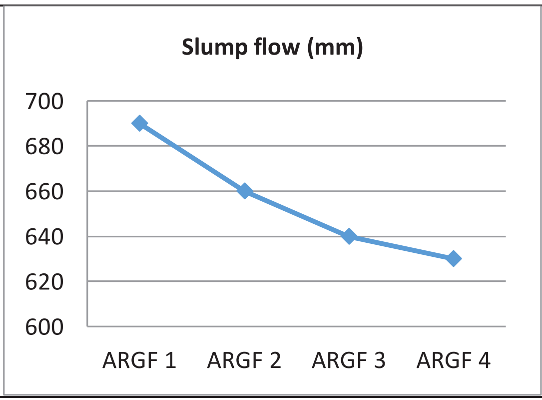

Fig 2 Slump Test of ARGF With SCC 6 Mix

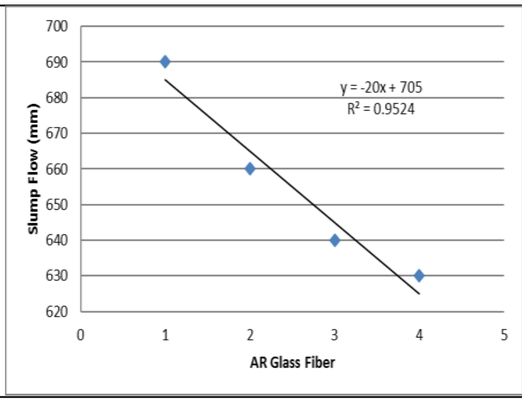

Fig 7 (a) Slump flow

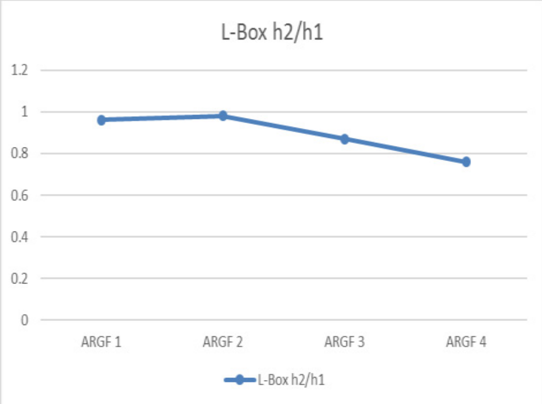

Fig 3: L box test of ARGF with SCC 6 Mix

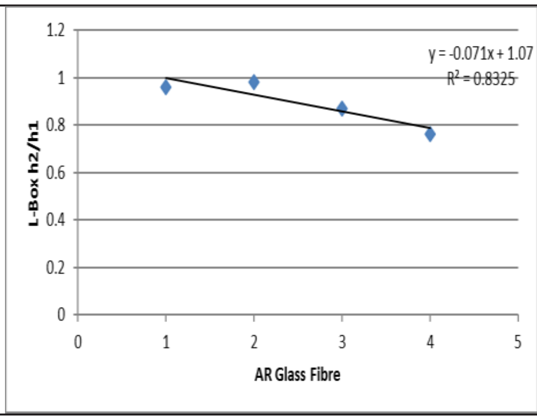

Fig 7 (b) L box

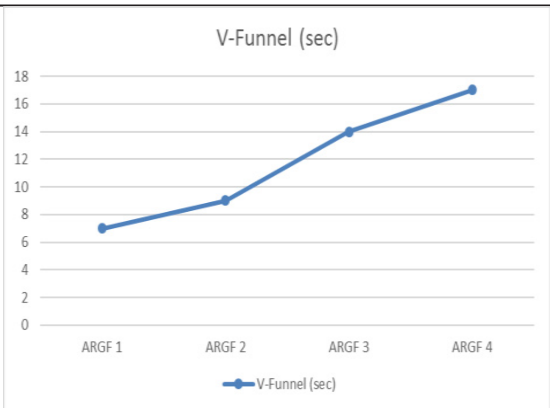

Fig 4: V-Funnel test of ARGF with SCC 6 Mix

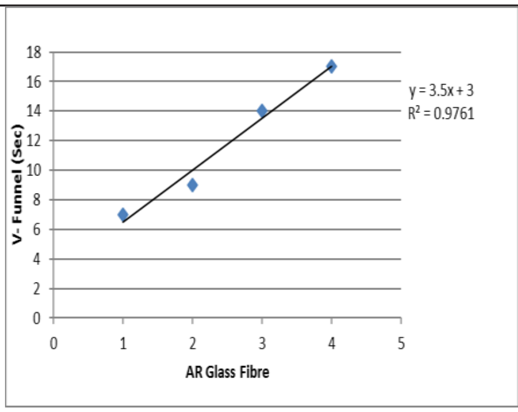

Fig 7 (C) V Funnel

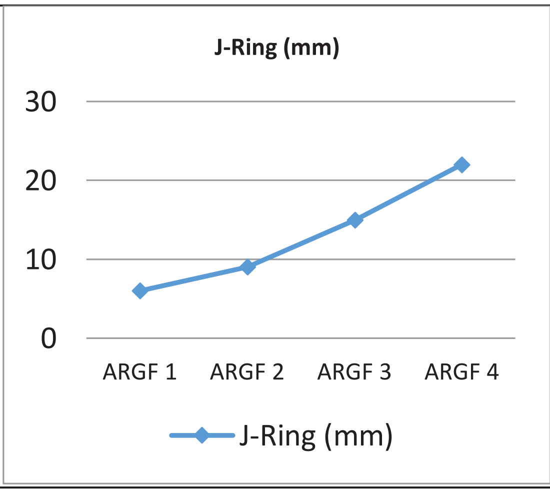

Fig 5: J-Ring test of ARGF with SCC 6 Mix

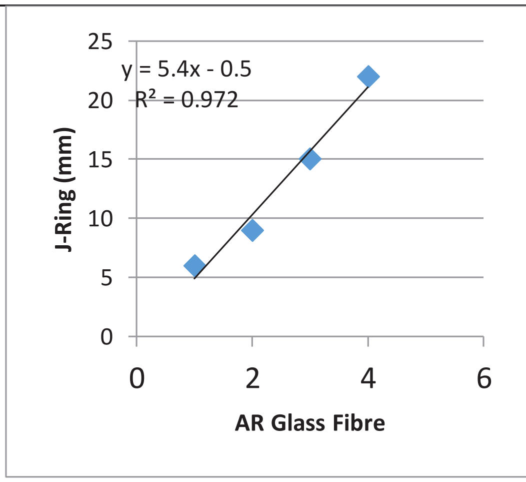

Fig 7 (d) J-Ring

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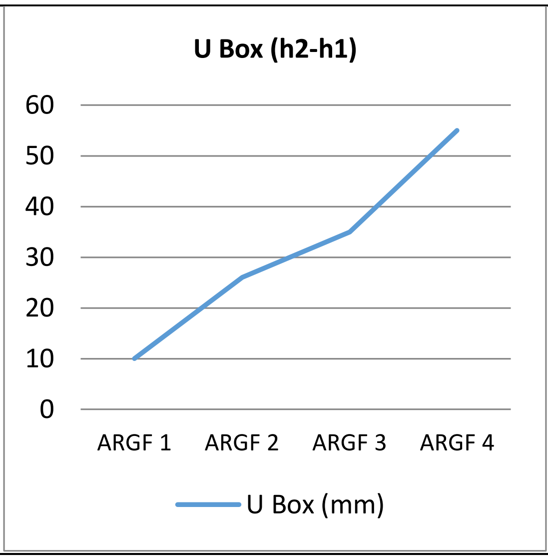	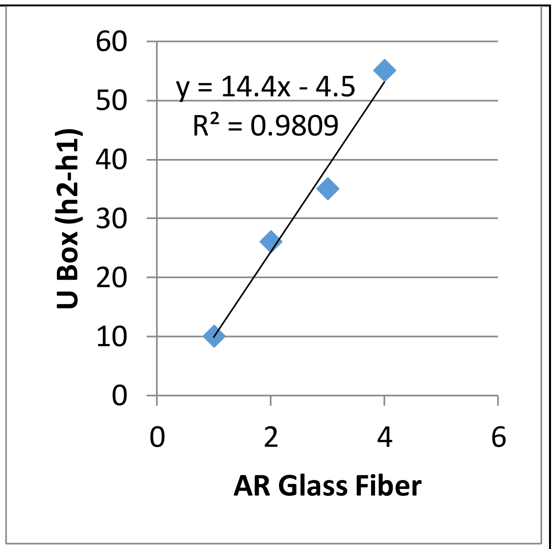
Fig 6: U Box of ARGF with SCC 6 mix	Fig 7(e) U Box
	Fig 7 Developed equations related to AR Glass fiber

3.2 Test on Hardened Concrete

3.2.1 Compressive strength

The compressive strength of concrete is a highly desirable characteristic of toughness. Fibre, addition to concrete, can have two opposing effects on its compressive strength, increasing or decreasing its value. Heba et al. 2011 Reinforcement using plain fibers Concrete could efficiently arrest the advancement of cracks and, as a result, raise the compressive strength value. [12] When the proportion of fibers in the mix is increased by 0.6 percent, the compressive strength of the mix increases. As the percentage of fibers in the mix grows, the compressive strength of the mix decreases. In this study, cube specimens of 7 as SCC1 to SCC7 (with a nominal mean of 3 cubes) were cast using quantities of 5, 10, and 15% silica fume and 10, 15, and 20% fly ash in cement with curing times of 7, 14, and 28 days. The specimen was continuously tested on uniform testing equipment with a load capacity of 200 kN until it failed. Every replacement was tested to determine the compressive strength displayed in Table7. The SCC 6 mix is the optimum proportion shown in Fig 8. It was found from that result. The optimal SCC 6 mix proportion incorporates the following percentages of ARGF: 0.1, 0.2, 0.3, and 0.4 percent, displayed in Table 8. Fig 9 revealed that the presence of AR glass fiber increased compressive strength to 39–55 MPa after 28 days. This finding suggests that increasing fiber porosity is less effective than increasing crack-bridging ability.

Table 7 Compressive Strength on SCC

Sl. No	Silica fume (%)	Fly ash (%)	Identification	Compressive strength (Mpa)		
				7 days	14 days	28 days
1	15	10	SCC 1(PPC)	14.33	18.81	19.47
2	15	10	SCC 2(OPC)	24.88	24.77	15.06
3	10	15	SCC 3(OPC)	16.44	17.27	25.3
4	10	10	SCC 4(OPC)	20.16	24.78	23.48
5	10	20	SCC 5(OPC)	20.89	30.5	29.1
6	5	10	SCC 6(OPC)	28.98	30.86	30.42
7	5	15	SCC 7(OPC)	25.76	19.55	22.8

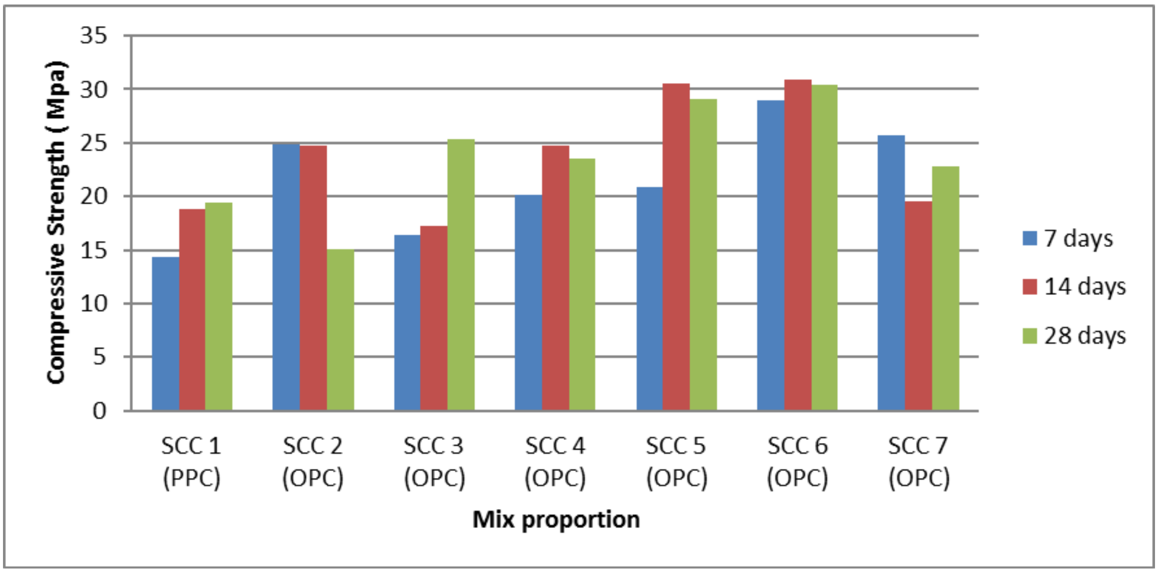

Fig 8 Compressive Test on SCC

Table 8 Compressive Strength On SCC With AR Glass Fibre

S.No	SCC 6 + % of AR Glass Fiber	Mix ID	Compressive Strength (MPa)		
			7 days	14 days	28 days
1	0.1	ARGF 1	39.52	37.32	39
2	0.2	ARGF 2	41.77	42.82	42.09
3	0.3	ARGF 3	50.72	53.63	55.56
4	0.4	ARGF 4	54.63	55.21	55.6

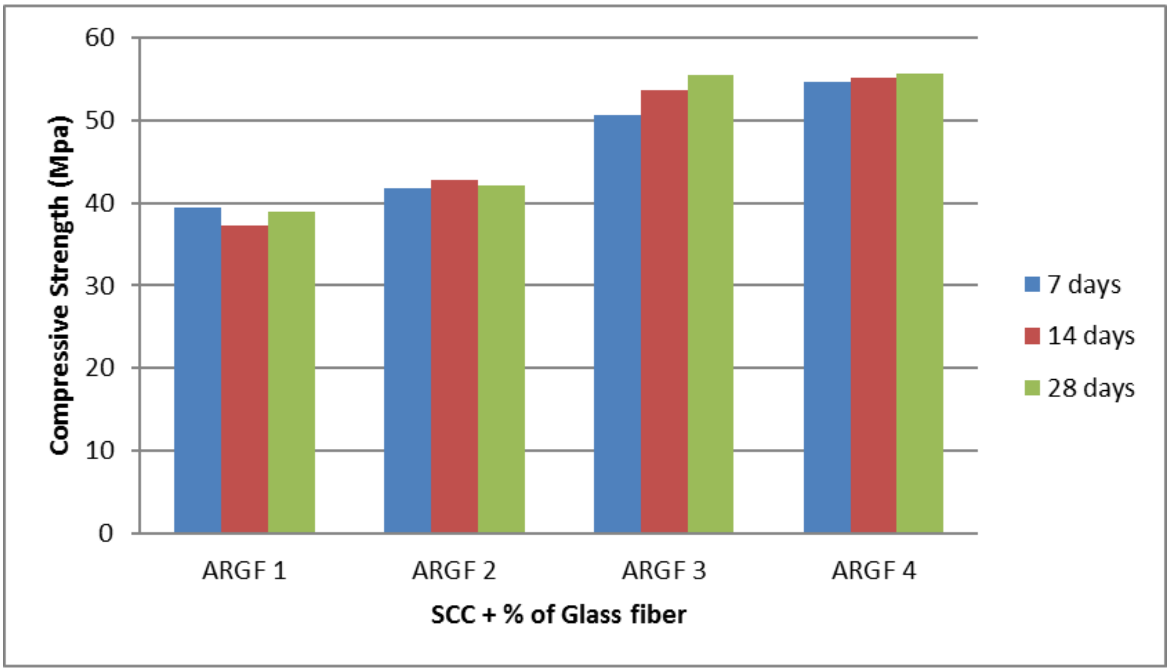

Fig 9 Compressive Strength Test on SCC with AR Glass fibre

3.2.2 Split Tensile strength

To test the split tensile strength, cylinder specimens with standard dimensions of 150mm diameter and 300mm length were cast. [18] Because plain concrete is prone to cracking when subjected to tensile loading, tensile strength is an important attribute. In general, adding fibre to concrete improves the structural integrity of the concrete. [9] The use of silica fume and fibre in concrete mixtures simultaneously has advantages: Increases splitting tensile strength by improving both the aggregate-paste bond and the fiber /matrix bond characteristics. [12] To understand the concrete's essential qualities, it's necessary to compute tensile strength. Concrete is weak in tension and cannot withstand further tensile loads. However, determining the load at which concrete members may break necessitates determining the ductile strength of the concrete. Table 9 revealed that, 3 cylinder were casting for each mix (SCC1 to SCC 7) to evaluate the tensile strength of hardened concrete at 7,14 and 28 days. Fig 10 Optimum mix identified from the above mix and then to add the percentage of ARGF (0.1 to 0.4) with optimum mixes of SCC 6 in Table 10. Fig 11 The maximum tensile strength was noted as 4.6 MPa in SCC 6 mix with 0.4 % of ARGF. Glass fibre adds to better strength and performance, as evidenced by the tensile strength test. Furthermore, using Fly ash, silica fume and fibre in concrete mixtures has a benefit: it improves splitting tensile strength by improving both the aggregate-paste bond and the fiber/matrix bond qualities.

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Table 9 Split Tensile Strength on SCC

Sl. No	Silica fume (%)	Fly ash (%)	Mix ID	Tensile strength (Mpa)		
				7 days	14 days	28 days
1	15	10	SCC 1	0.34	0.39	0.35
2	15	10	SCC 2	0.44	0.36	0.37
3	10	15	SCC 3	0.3	0.3	0.21
4	10	10	SCC 4	0.53	0.33	0.44
5	10	20	SCC 5	0.44	0.33	0.36
6	5	10	SCC 6	0.46	0.44	0.48
7	5	15	SCC 7	0.45	0.58	0.27

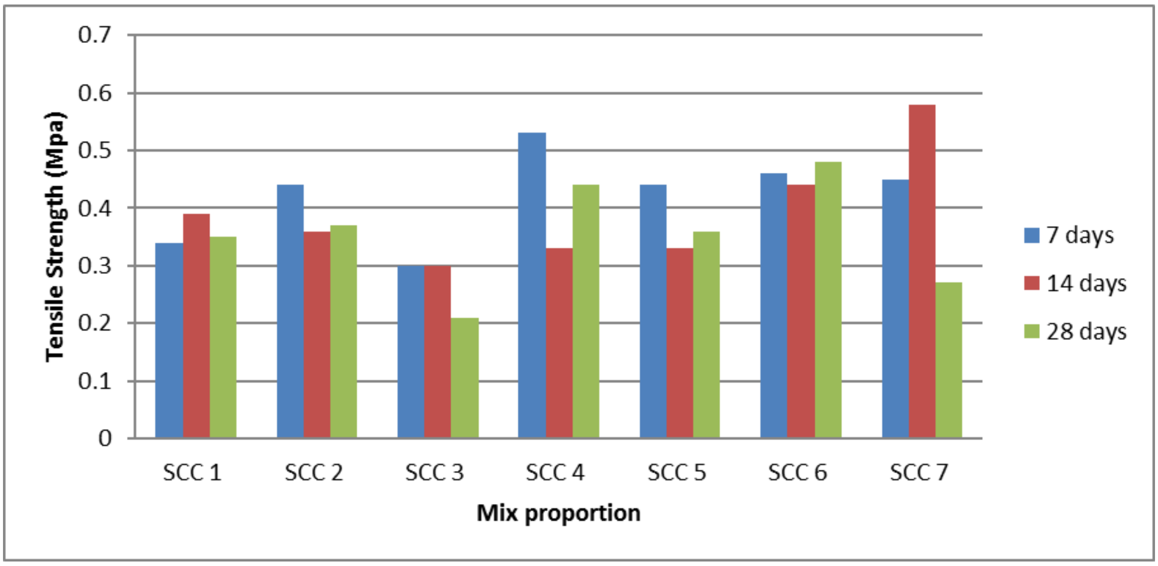

Fig 10 Split Tensile Strength Test on SCC

Table 10 Split Strength On SCC With AR Glass Fibre

S.No	SCC 6 + % of AR Glass Fiber	Mix ID	Tensile Strength (MPa)		
			7 days	14 days	28 days
1	0.1	ARGF 1	4.16	4.23	4.19
2	0.2	ARGF 2	4.36	4.32	4.25
3	0.3	ARGF 3	4.43	4.35	4.49
4	0.4	ARGF 4	4.6	4.5	4.7

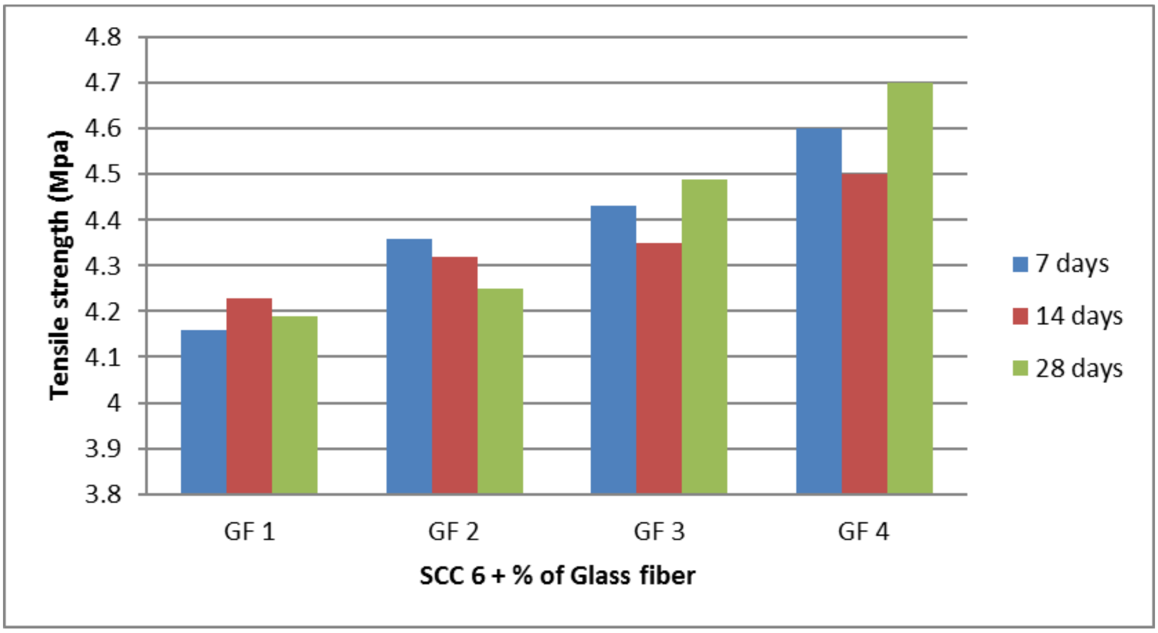

Fig 11 Tensile Strength Test on SCC with AR Glass fibre

3.2.3 Flexural strength

Concrete flexural tests were conducted using prism specimens of 500 mm by 100 mm by 100 mm. The sample was loaded gradually into the bending strength testing apparatus. It is indicated the load upon failure. The flexural strength is subsequently calculated after seven, fourteen and twenty-eight days. Table 11 revealed that the addition of silica fume and fly ash of varying percentages by replacement of cement. From that test, they got the optimum result as an SCC 6 mix in fig 12. The proportion of SCC 6 mix is 5% silica fume and 10% fly ash for cement replacement. Flexural strength is the ability of a material to endure bending forces that are applied perpendicular to its axial direction. Furthermore adding varying percentage of ARGF as 0.1 to 0.4 in the SCC mix revealed in Table 12. The maximum flexural strength was attained in 0.4 % ARGF with SCC 6 mix as 14.8 MPa in Fig 13

Table 11 Flexural Strength On SCC

S.no	Silica fume (%)	Fly ash (%)	Mix ID	Flexural strength (Mpa)		
				7 days	14 days	28 days
1	15	10	SCC 1	5	7.5	7
2	15	10	SCC 2	11.5	8.9	5.6
3	10	15	SCC 3	5	5.2	5.4
4	10	10	SCC 4	10.7	8.2	10.4
5	10	20	SCC 5	9.2	10.2	10.5
6	5	10	SCC 6	12.7	14.8	14.6

7	**5**	**15**	**SCC 7**	**11.5**	**11.5**	**6.3**

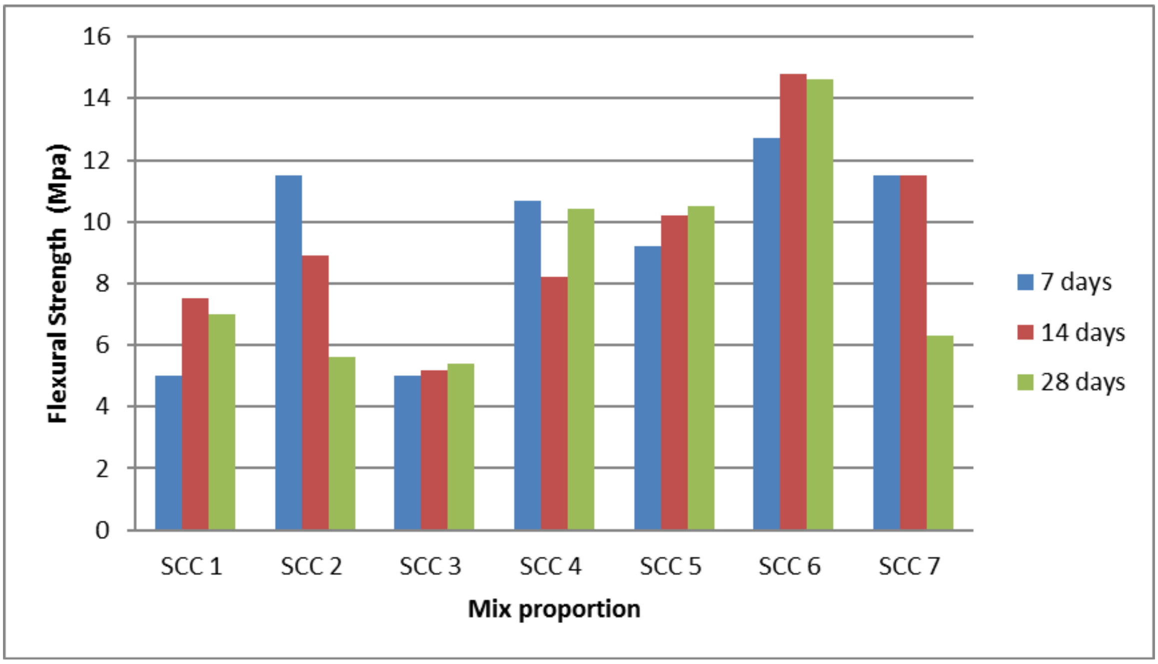

Fig 12 Flexural Strength Test on SCC with AR Glass fibre

Table 12 Flexural Strength Test On SCC With ARGlass Fibre

S.No	**SCC 6 + % of AR Glass Fiber**	**Mix ID**	**Flexural Strength (MPa)**		
			7 days	**14 days**	**28 days**
1	0.1	ARGF 1	13.45	14.17	12.37
2	0.2	ARGF 2	12.75	13.56	13.86
3	0.3	ARGF 3	14.32	12.69	13.9
4	0.4	ARGF 4	13.93	13.29	14.08

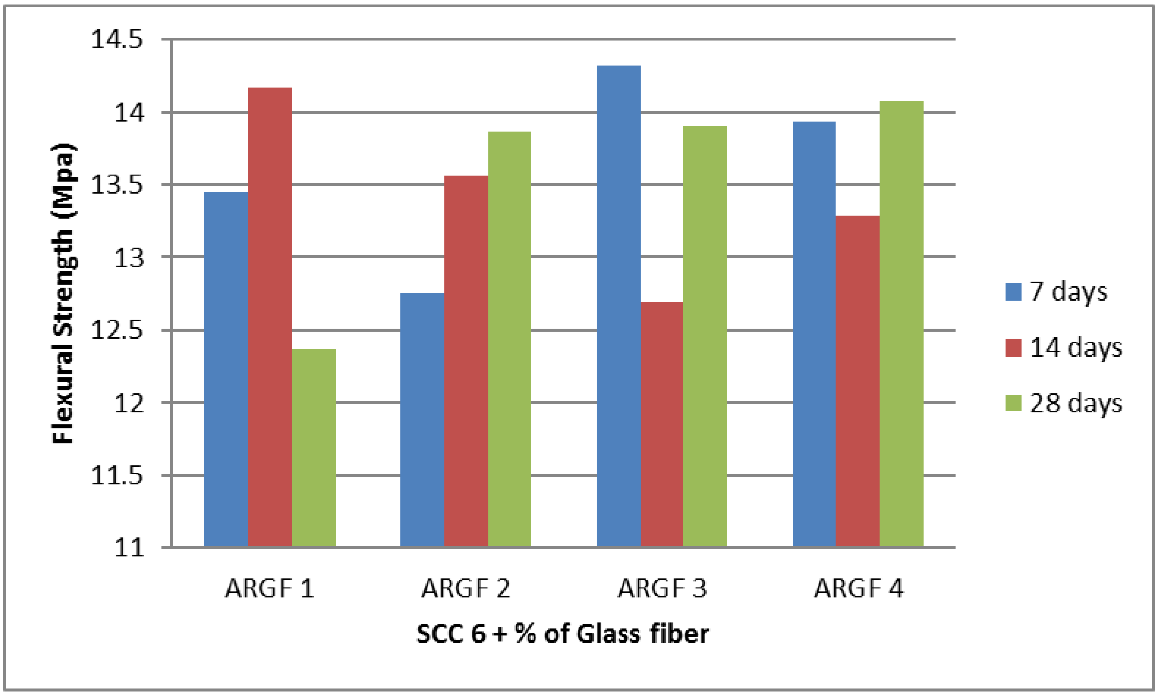

Fig 13 Flexural Strength Test on SCC with AR Glass fibre

Fig 14 (a) Compressive strength (b) Split Tensile strength (c) Flexural Strength

4. Conclusions

Self-compacting concrete is currently more necessary than ever before because of structural requirements, member illness, and the need to increase structure durability. The requirement for high performance concrete, durability, and SCC is increasing globally, and the traditional method of compacting may not always be practical depending on the site conditions. So instead of using ordinary concrete, let's mix self-compacting concrete, which self-compacts on its own. The subsequent findings were drawn based on the experimentation, leading to certain conclusions.

- The experimental observations proved that the replacement of silica fume by 5% and fly ash by 10% in cement is found to carry higher loads than that of other combinations.

- Adding AR glass fiber to the self-compacting concrete has provided flexible concrete. It also enhances strength
- The higher the percentage of glass fiber, the higher the concrete's compressive strength, flexural strength, and split tensile strength values

References

[1] S. H. V. Mahalakshmi and V. C. Khed, Materials Today: Proceedings, vol. **27**, pp. 1061–1065. Jan. (2020)
[2] A. F. Bingöl and I. Tohumcu Materials & Design, vol. **51**, pp. 12–18, October (2013).
[3] S. Ahmad, A. Umar, and A. Masood, Procedia Eng,vol. 173, pp. 807–813. January(2017).
[4] H. A. Mohamed, Ain Shams Eng J, vol. **2**, no. 2, pp. 79–86, July (2011).
[5] V. Gokulnath, B. Ramesh, and S. Suvesha, Materials Today: Proceedings, vol. **22**, pp. 788–792, January(2020)
[6] O. Gencel, W. Brostow, T. Datashvili, and M. Thedford Compos Interfaces, vol. **18**, no. 2, pp. 169–184, January(2011).
[7] R. Prakash, S. N. Raman, N. Divyah, C. Subramanian, C. Vijayaprabha, and S. Praveenkumar, Construction Building Materials, vol. **290**, July (2021)
[8] C. K. Mahapatra and S. V. Barai, Construction Building Materials, vol. **160**, pp. 828–838, January (2018)
[9] M. Mastali and A. Dalvand, Construction Building Materials, vol. **125**, pp. 196–209, October (2016)
[10] M. Benaicha, X. Roguiez, O. Jalbaud, Y. Burtschell, and A. H. Alaoui, Construction Building Materials, vol. **84**, pp. 103–110, June (2015)
[11] V. N. Zarnaghi, A. Fouroghi-Asl, V. Nourani, and H. Ma, Construction Building Materials, vol. **193**, pp. 557–564, December (2018)
[12] T. Jeevetha, S. VijayaShanthy, A. Sivakumar, and N. B. Singh, Materials Today: Proceedings, vol. **45,** pp. 708–712 January (2021).
[13] J. Sanjeev and K. J. N. Sai Nitesh Materials Today: Proceedings, vol. **27**, pp. 1559–1568. January (2020).
[14] S. Ahmad and A. Umar, J Building Engineering, vol. **17**, pp. 65–74, May (2018)
[15] E. R. Sujatha, P. Atchaya, S. Darshan, and S. Subhashini, Road Materials and Pavement Design, vol. **22**, no. 10, pp. 2384–2395, October (2021).
[16] 'Specification and Guidelines for Self-Compacting Concrete', (2002). [Online]. Available: www.efnarc.org
[17] H. A. F. Dehwah, Construction Building Materials, vol. **26**, no. 1, pp. 547–551, January (2012).
[18] ASTM C-0618, Standard Specification for Coal Fly Ash and Raw or Calcined
[19] Natural Pozzolan for Use, Annu B ASTM Stand. (2010) 3–6