Development of Self Compacting Geo Polymer Hybrid Fiber-Reinforced Concrete Using Highly Potential Sustainable Materials

B. Narendra Kumar, P. Pavan, and G. Vinod Kumar

1 Introduction

In the present world, the global warming is the major crisis for the sustainable development [1]. The utilization of waste products obtained from the power plant can be used as replacement to cement and decrease the environmental effect [2]. The research has led to the substitute of cement with the Fly Ash [3], which deals with the geo polymer concrete [4] incorporating SSC which is cement free [5]. The geo polymer concrete is difficult to place, but with ease of self-compacting concrete the SCGPC showed exceptionally good flow [6, 7]. In GPC, the silica and alumina content are more which undergoes chemical reaction and form C–S–H gel [8] called Geo polymerization. The other key factor for geo polymer concrete is alkali activated materials like sodium silicate and sodium hydroxide which acts as a binder [9–11]. The Cementitious materials like Fly Ash, GGBS and Metakaolin [12] reacts with alkali activated materials and improves the workability of the mix [13, 14]. The SCGPHFC incorporates combination of two fibers like steel fiber [15] and PVA [16] fiber. To design the SCGPHFC mix the serviceability of the concrete plays a key role for the workability, hardened properties, and durability properties which are interlinked with every property of the concrete. For, the workability of concrete the following test methods are determined which influences the strength and durability properties of concrete [17–19]. The strength properties for SCGPHFC are determined for the 7 days of ambient curing. Durability tests like abrasion resistance of concrete, acid resistance of concrete and rapid chloride permeability test (RCPT) of concrete were conducted [20–22].

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2 Significance of Research

This research focuses on incorporating cementitious materials such as GGBS, Metakaolin and Fly ash along with hybrid fibers like Steel fibers and PVA fibers to enhance the strength and performance properties of concrete. The aim is to produce green concrete having desirable strength and durability. The main intention of this work is to evaluate the performance of self-compacting geopolymer hybrid fiber-reinforced concrete by using steel fibers and PVA fibers in different proportions.

3 Research Gap

- The impact of supplementary cementitious materials with hybrid fibers on fresh and hardened qualities, as well as durability features, has not been fully determined in existing research surveys.
- Different doses of hybrid fibers in geopolymer concrete are being investigated.

4 Materials and Methods

Class F fly ash is used which is obtained from a by-products of industrial waste from a thermal power plant [23, 24] which consists mostly of alumina and silica which is classified according to the ASTM C 618 [3]. The GGBS was obtained from the steel industry supplied by local suppliers available in Hyderabad which have a specific gravity of 2.7 which is classified according to the ASTM C 9892018 [25–27]. The Metakaolin [MK] is supplied by local suppliers and was classified according to ASTM C 618 N as having specific gravity is 2.6 which is obtained from calcined kaolin [8] clay. The NaOH is taken in the form of pellets which is prepared for 8 M concentration with prior to one day of the mix. The sodium silicate was available in the form of liquid gel from the locally available with configuration of Na_2O, SiO_2 and water [28, 29]. The aggregates were used in the present work are locally available conforming to IS 383:2016 [30, 31]. The Super Plasticizer of Master Glenium ACE 30 which was available in BASF industries which is the admixture of poly carboxylic ether polymer with high early strength gain according to the IS 9103:1988 [32–34]. The steel fiber having the aspect ratio of 67 and density of 7800 kg/m^3. The PVA fiber is unique in their ability [16] to create the molecular bond with mortar with the aspect ratio [35, 36] of 315 and density of 1190 kg/m^3.

5 Mix Proportioning of SCGPHFC

The mix proportioning of SCGPHFC, the powder content and aggregates are constant for all the mixes. Overall, the six mixes were changing in the percentage of fibers with the total percentage of fibers is 1.5%. Table 1 shows the mix proportioning of SCGPHFC.

6 Mixing and Casting

For homogeneous mixing of concrete 80 L capacity electrically operated pan mixer was used mixing of concrete The total amount of aggregates and powder content are added simultaneously and alkali activator solution, water, and superplasticizer is added one after the other for the proper mix for uniform mixture as shown in Fig. 1. The mixed SCGPHFC was deposited into the molds. After 24 h, the specimens were detached and molds were kept for ambient temperature for 7, 28, and 90 days after performing all the workability.

7 Experimental Investigation on Workability

The workability of SCGPHFC was evaluated by performing the tests according to ASTM C 143–15 as shown below in the Figs. 2, 3 and 4.

The results of SCGPHFC mixes are depicted in Figs. 5, 6 and 7. It was observed that the mix of SCGPHFC 1, that is, mix without fiber showed the greater flow than other mixes with fiber. The SCGPHFC1 showed the values 650 mm for slump flow, 0.86 for L-Box test and 2.5, 7.5 for V-funnel tests whereas the optimum mix SCGPHFC 5 showed lowest values 540 mm for slump flow, 0.83 for L-Box test and 4.5,10 for V-funnel tests. Concrete flow is reduced due to non-homogeneity created by addition of fibers and with increase in the proportion of fiber content, the workability decreased as shown.

8 Compressive Strength

Compressive strength of concrete is conducted by cubes of size 150 mm as shown in Fig. 8, which was cast, cured, and tested at the end of 7, 28 and 90 days as shown in Table 2 as per IS 516 [37]. The SCGPHFC 5 mix showed highest value of compressive strength and for the next proportion a decline in strength was observed however the value was not less than SCGPC 1, that is, mix without fiber. Due to higher density of steel fiber, the gain in strength was more compared to PVA fiber.

Table 1 Mix designation

	FA (Kg/m^3)	GGBS (Kg/m^3)	MK (Kg/m^3)	NaOH (Kg/m^3)	Na_2SiO_3 (Kg/m^3)	Water	SP	Fiber	
								PVA	Steel
SCGPHFC 1	500	50	50	96	144	60	12	–	–
SCGPHFC 2	500	50	50	96	144	60	12	–	1.5%
SCGPHFC 3	500	50	50	96	144	60	12	0.25%	1.25%
SCGPHFC 4	500	50	50	96	144	60	12	0.5%	1%
SCGPHFC 5	500	50	50	96	144	60	12	0.75%	0.75%
SCGPHFC 6	500	50	50	96	144	60	12	1%	0.5%

Fig. 1 Pan mixer

Fig. 2 Slump flow of concrete

Fig. 3 V-Funnel test

Fig. 4 L-Box test

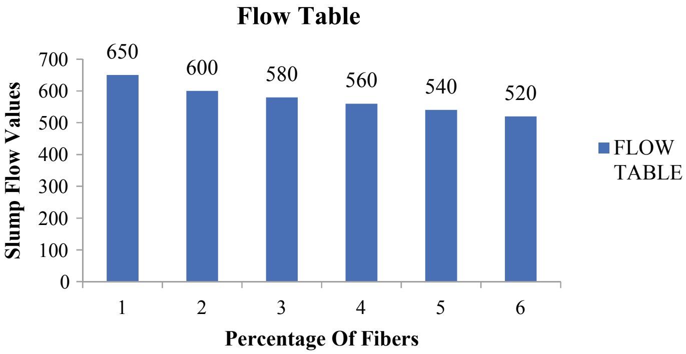

Fig. 5 Slump flow For SCGPHFC

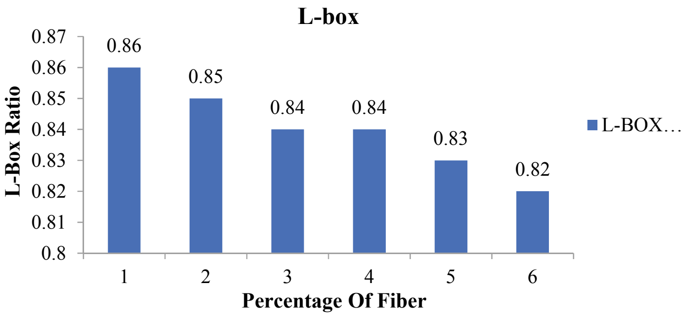

Fig. 6 L-Box values for SCGPHFC

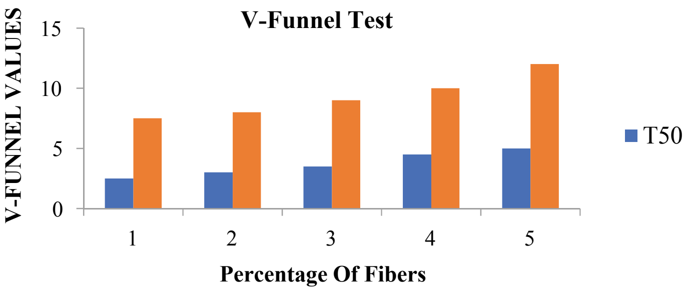

Fig. 7 V-Funnel test for SCGPHFC

Due to the constant powder content, a polymerization reaction takes place, which enhances the compressive strength by 26.3%, 29%, 30% at 7 days, 28 days, and 90 days when compared to the mix without fibers. Presence of equal proportions of fibers in the mix SCGPHFC 5, that is, 0.75% of PVA and steel fiber are responsible for having more strength properties compared to other mixes having different

Fig. 8 Compression testing machine

Table 2 Compressive strength

MIX selection	Compressive strength (MPa)		
	7 Days	28 Days	90 Days
SCGPHFC 1	29.8	38	41.2
SCGPHFC 2	37.63	49	53.59
SCGPHFC 3	39.85	51.8	56.19
SCGPHFC 4	42.63	52.6	61
SCGPHFC5	43.1	54.8	67
SCGPHFC6	40.8	52.3	55.6

percentages of fibers. The compressive strength for SCGPHFC 5 has 67 Mpa for 90 days as shown in above Fig. 9.

9 Split Tensile Strength

Split Tensile strength is conducted on a standard sample having a 150 mm diameter and 300 mm of height [38]. The specimens were cast, cured, tested and the experimental values are shown in the Table 3. The Split tensile strength test was performed according to IS 516 [37]. Higher value of tensile strength was attained for SCGPHFC 5 and for the later mix i.e. SCGPHFC 6 the strength decreased. Steel fiber has more tensile strength properties when compared to the PVA fiber. And thus the reduction in strength for SCGPHFC 6 is attributed to decrease in percentage of steel fiber.

The strength was increased by 58.2%, 57.5%, 58.1% at the end of 7 days, 28 days, 90 days due to the presence of fibers. The addition of fibers thus imparts good tensile strength to concrete. As the percentage of fiber increases the strength also increases

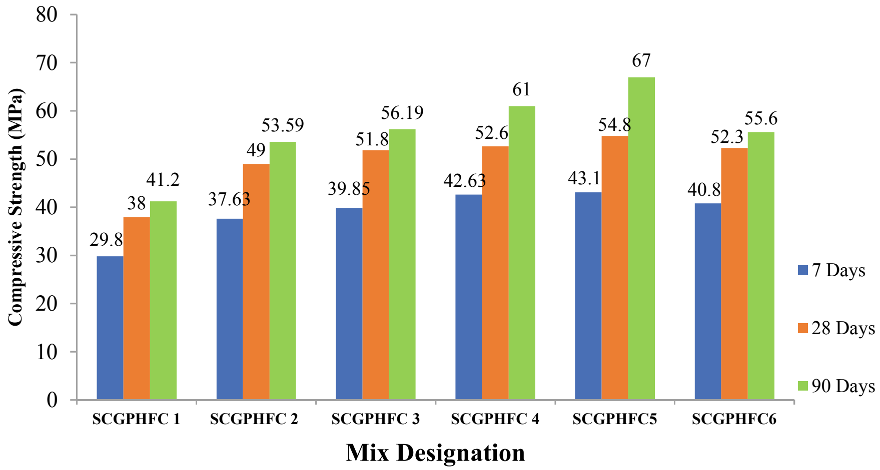

Fig. 9 Compressive strength for SCGPHFC

Table 3 Split tensile strength for SCGPHFC mixes

Mix designation	Split tensile strength (MPa)		
	7 Days	28 Days	90 Days
SCGPHFC 1	3.5	4.3	4.8
SCGPHFC 2	5.6	6.9	7.6
SCGPHFC 3	6	7.41	8.2
SCGPHFC 4	6.5	8	8.84
SCGPHFC 5	7	8.7	9.54
SCGPHFC 6	6	7.6	8.4

i.e. for SCGPHFC 5 due to the constant powder content, good geo-polymeization reaction occurs and addition of equal proportions of both fibers, that is, 0.75% of PVA and steel fiber, increased the strength properties compared to other mixes having different percentages of fibers. The tensile strength for SCGPHFC 5 was 9.54 Mpa as shown in Fig. 10.

10 Flexural Strength

The test is performed on samples of size 150 mm × 150 mm × 100 mm. These specimens are cast, cured, and tested at 7 days, 28 days and 90 days as shown in the Fig. 11 and Table 4. Based on the results, increase in flexural strength was observed to be highest for SCGPHFC 5 and for the later mix SCGPHFC 6 the strength was

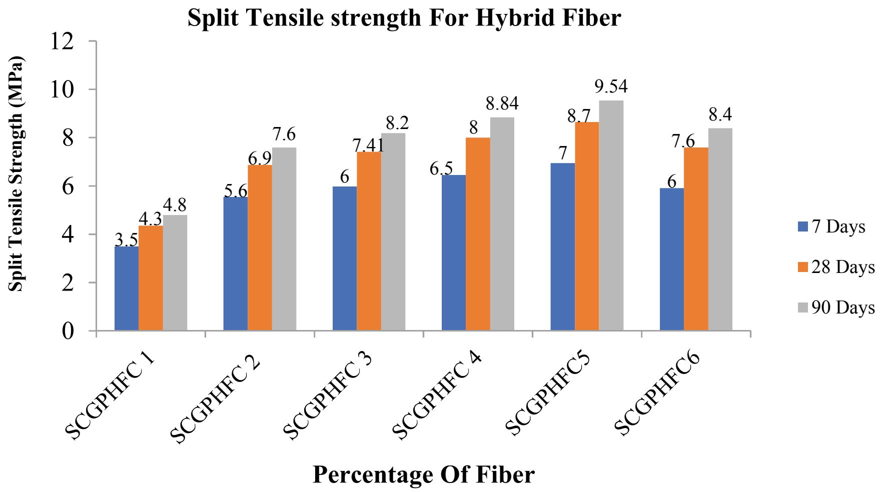

Fig. 10 Split tensile strength

decreased, however the value was not less than the mix without fiber. The reason for reduction in trength is due to lesser proportion of steel fiber in the latter mix.

The strength increases by 25.4%, 23.6%, 21.6% at the end of 7, 28, 90 days due to the presence of fibers. As the percentage of fiber increases the strength increases,

Fig. 11 Flexure testing machine

Table 4 Flexural strength

Mix designation			
	7 Days	28 Days	90 Days
SCGPHFC 1	4.01	5.7	5.92
SCGPHFC 2	6.34	9.01	9.37
SCGPHFC 3	6.84	9.73	10.11
SCGPHFC 4	7.38	10.5	10.91
SCGPHFC 5	7.97	11.34	12.78
SCGPHFC 6	7.01	9.97	10.36

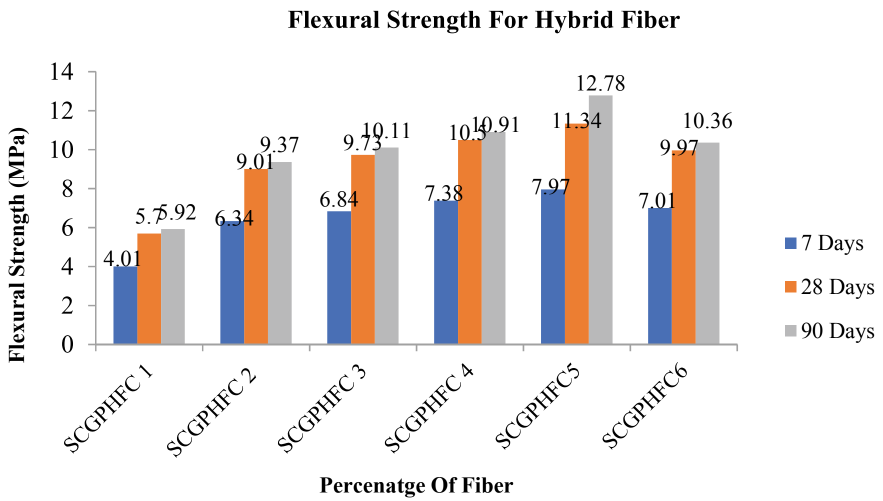

Fig. 12 Flexural strength

that is, for SCGPHFC 5 mix having 0.75% of PVA and steel fiber the concrete matrix properties are inhanced which increasing the flexural property compared to SCGPHFC 1. The strength for SCGPHFC 5 was 12.78 Mpaas shown in the Fig. 12.

11 Conclusions

Conclusions from the experimental investigation of Self Compacted Geo Polymer Hybrid Fiber Concrete are:

1. The mix proportions adopted in this experiment included by-products like fly ash, GGBS, metakaolin which satisfied the EFNARC guidelines. The workability of the concrete decreases as the dosage of fiber increases and fiber is said to induce non-homogeneity to concrete.

2. For the mix SCGPHFC 5 the Compressive strength, Split Tensile strength, and Flexural strength were maximum compared to the other mixes.
3. The compressive strength was increased by 16.7%, Split tensile strength was increased by 17.2% and flexural strength was increased by 12.67% for 7 days to 28 days, respectively.
4. The future scope of the work is the sustainable development of concrete with different mineral admixtures and different fibers in the practical applications of concrete.

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