Study of Flexural Behavior of Hybrid Fibre Reinforced Geopolymer Concrete Beam

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Abstract: ***Concrete is the most common building material in the world and its use has been increasing during the last century as the need for construction projects has escalated. One of the potential materials to substitute for conventional concrete is geopolymer concrete (GPC). GPC is an inorganic alumino-silicate polymer synthesized from predominantly silicon, aluminum and by-product materials such as fly ash, Ground Granulated Blast Slag etc. The main objective of this study is to investigate the impact of steel fibres and hybrid polypropylene- steel fibres on the mechanical flexural behavior of GPC. Crimped steel fibre with varying percentages (0%, 0.25%, 0.5%, 0.75% & 1%) is adopted in this study. And then polypropylene fibre is added to the optimum steel fibre mix with varying percentages (0%, 10%, 20%, 30% & 40%). The addition of fibres changes its brittle behavior to ductile with significant improvement in tensile strength, tensile strain, toughness and energy absorption capacities. For curing, temperature was fixed at room temperature for 24 hours. The concrete specimens were tested for mechanical properties of concrete namely cube compressive strength, split tensile strength, flexural strength and other tests were conducted for cement, chemical admixture, coarse aggregate & fine aggregate. The results of the experimental program reveal that mechanical properties of GPC are improved with the addition of fibres and also improve the load carrying capacity of beams.***

Keywords: Geopolymer concrete, Steel fibre reinforced concrete, Hybrid fibre reinforced concrete, Steel fibre, Polypropylene fibre.

1. Introduction

Portland cement concrete is a mixture of Portland cement, aggregates, and water. Concrete is the most often-used construction material throughout the world because of its mouldability, durability, and resistance to fire and energy efficiency. Demand for concrete as construction material is on the increase and so is the production of cement. The production of one tonne of cement liberates about one tonne of CO_2 to the atmosphere. In order to address environmental effects associated with Portland cement, there is need to develop alternative binders to make concrete. The recent environmental awareness in construction industry promotes the use of alternative binders to partially or fully replace the cement.

One of the efforts to produce more environmentally friendly concrete is to replace the amount of Portland cement in concrete with by-product materials such as fly ash. Another effort to make environmentally friendly concrete is the development of inorganic alumina-silicate polymer, called Geopolymer, synthesized from materials of geological origin or by-product materials such as fly ash that are rich in silicon and aluminium. In the future, fly ash production will increase, especially in countries such as China and India. Accordingly, efforts to utilize this by-product material in concrete manufacture are important to make concrete more environmentally friendly. Concrete exhibits brittle behaviour due to its low tensile strength. The addition of fibres, either short or continuous, changes its brittle behaviour to ductile with significant improvement in tensile strength, tensile strain, toughness and energy absorption capacities. The binder in the Fibre Reinforced Cement Composites (FRCCs) is mainly Portland cement. Efforts have been made to replace the cement based binder in the current FRCC with ‘‘geopolymeric’’ binder resulting in Fibre Reinforced Geopolymer Composites (FRGCs), which is greener than the former one.

The objectives of the work can be summarized as follows:

- To develop the proper mix proportion for geopolymer concrete.
- To study the effect of steel fibres on the mechanical properties of fly ash based GPC and find out its optimum.
- To study the effect of hybrid fibres on the flexural behavior of steel fibre reinforced GPC.
- To compare the load deflection behavior, first crack load, crack pattern and failure mode, ductility index, energy absorption capacity and ultimate load of HFRGPC beams with GPC beams.

2. Preliminary Investigation

It includes the material characterization, mix design, properties of fresh concrete and properties of hardened concrete. The main objective of the study was to obtain the mix proportions for GPC and find out the optimum percentage of steel fibre. For the same purpose the material properties of the constituent materials were first determined.

2.1 Test on constituent materials

Flyash : Class F flyash of specific gravity 2.36 obtained from Mettur thermal power plant was used for the experiments. Ground Granulated Blast Furnace Slag : Obtained from steel plant, Karnataka of specific gravity 3.08 was used for the study. 50% of flyash was replaced with GGBS in the study.

Fine aggregate : M sand is used as fine aggregate. M sand passing through 4.75mm IS sieve conforming to grading zone

II of IS 383:1970 was used. Specific gravity and fineness modulus of Sand used were 2.38 and 2.84 respectively.

Coarse aggregate: Coarse aggregate of maximum size 20 mm from local source was used.

Alkaline liquid: A combination of sodium hydroxide and sodium silicate solutions was used as the alkaline liquid to activate fly ash. A sodium hydroxide solution was prepared by dissolving sodium hydroxide flakes in water. It was obtained from venad lab equipments and chemicals, kollam.
Steel Fibre : Crimped steel fibres having diameter 0.5 mm and length 25 mm were used for the present study. fibre was purchased from STEWOLS INDIA (P) Ltd.

Figure 1: Crimped steel fibre

Polypropylene Fibre: Locally available Polypropylene fibres of length 12mm and aspect ratio 318 was used for the study.
Superplasticizer: Naphthalene based superplasticizer Conplast SP-430, supplied by M/s Fosroc Chemical (India) Pvt. Ltd. was used as superplasticizer.

Water: Potable water is generally considered as being acceptable. Hence water available in the college water supply system was used for casting.

Reinforcing bars : Main reinforcement consists of 10mm ϕ and 8mm ϕ HYSD steel bars of Fe 415 grade. 6mm ϕ steel bars were used as stirrups.

A. Mix Design

Inorder to arrive the mix proportion for the present study, the optimum values of different parameters were adopted from previous literature. The previous studies on Geopolymer concrete. (M I Abdul Aleem and P D Arumairaj, 2012) used a mix proportion of fly ash: Fine Aggregate: Coarse Aggregate are 1:1.5:3.3 with a solution (NaOH & Na2SiO3 combined together) to fly ash ratio of 0.35. Trail mixes were arrived by slightly modifying the amount of solution. The ratio of activator solution-to flyash was selected 0.7 as the obtained mix with 0.7 was well workable. The details of the mix proportion for 1m^3 of concrete which has finalized is given in Table 1

Table 1: Details of mix

Materials	*Quantity (kg/m^3)*
Coarse aggregate	1260
Fine aggregate	540
Fly ash	171.43
GGBS	171.43
NaOH	24.02
Na_2SiO_3	183.67
Water	49.45

3. Mix Designation of Different Mixes with Varying Percentage of Steel Fibre

The concrete specimens were prepared by varying the proportion of steel fibres in the geopolymer concrete mix by adding the fibres from 0.25% to 1% by volume of concrete. Mix designation is presented in Table 2. Workability test were also carried out for each mix. The mechanical properties studied were cube compressive strength test, splitting tensile strength and flexural strength.

Table 2: Mix designation

Sl. No.	*Designation*	*Steel Fibre (%)*
1	GPC	0
2	SFRGPC 1	0.25
3	SFRGPC 2	0.5
4	SFRGPC 3	0.75
5	SFRGPC 4	1

Figure 2: Casting of Specimens

From critical evaluation of hardened properties of SFRGPC it can be seen that the addition of steel fibre increased the compressive strength, splitting tensile strength and flexural strength.

Table 3: Critical Evaluation on Strength of SFRGPC Mix

Mix designation	*Cube compressive strength (N/mm^2) 28 days*	*Flexural strength (N/mm^2) 28 days*	*Splitting tensile strength (N/mm^2) 28 days*
GPC	43.51	4.61	2.44
SFRGPC1	45.62	5.23	2.78
SFRGPC2	51.24	6.84	3.84
SFRGPC3	53.21	7.26	3.92
SFRGPC4	54.32	7.28	4.14

The increase was significant for mix with 0.5% steel fibre. And also the further increase in the amount of steel fibre resulted in poor workability, which mainly affects the further increase in flexural strength. Thus from the above discussion, SFRGPC2 can be selected as optimum steel fibre reinforced GPC mix for the further study.

4. Experimental Investigation

The main aim of the experimental investigation was to study the ductility and energy absorption capacity of fibre reinforced geopolymer concrete beams. The influence of steel and polypropylene fibre on first crack load, load deflection behavior, cracking pattern, energy absorption capacity, ultimate load and failure mode were studied. In the present study the effect of steel and polypropylene fibre in the flexural behavior of GPC beams were studied.

4.1 Mix proportion of hybrid fibre reinforced geopolymer concrete (HFRGPC)

Hybrid fibre composites were prepared by replacing crimped steel fibre having diameter 0.45mm, length 30mm and aspect ratio 66 with polypropylene fibre of length 12mm in volume fractions of 10%, 20%, 30%, 40% in the optimum steel fibre mix.

Table 4: Mix designation of HFRGPC mix

Sl. No.	*Designation*	*Steel Fibre (%)*	*Polypropylene Fibre (%)*
1	HFRGPC 1	90	10
2	HFRGPC 2	80	20
3	HFRGPC 3	70	30
4	HFRGPC 4	60	40

4.1.1 Details of Specimens

The specimens are standard cubes of 150mm side, cylinders of diameter 150mm and 300mm height, beams of size 500x100x100mm and 1200x100x150mm. Details of number of specimens are given in Table 5.

Table 5: Details of specimen

Sl. No.	*Specimen*	*Property*	*Size(mm)*	*Numbers*
1	Cube	Compressive strength	150 x150 x150	54
2	Cylinder	Splitting tensile strength	150mm diameter and 300mm height	27
3	Beam	Flexural strength	500 x100 x100	27
4	Large beam	Flexural pattern	1200x100x150mm	12
Total				120

4.1.2 Preparation and casting of specimens

For each mix of GPC, SFRGPC and HFRGPC mix six concrete cubes of size 150x150x150mm were casted for compressive strength test, three cylinders of 150mm diameter and 300mm height for splitting tensile strength test and three beams of size 500x100x100mm for flexural strength test were casted.

To study the flexural crack pattern total of 12 reinforced concrete beams of size 1200x100x150mm long were casted. Concrete was mixed in the laboratory. All specimens were vibrated with a mechanical vibrator. They were demoulded after 24 hour and were cured under room temperature curing. After 28 days, large beams were white washed for easy detection of crack.

Figure 3: Casting of beam specimen

Figure 4: Beams after white washing

4.1.3 Tests on Specimens

1. Study on workability
2. Study on strength
   - Compressive strength
   - Splitting tensile strength
   - Flexural strength
3. Study on flexural crack pattern

4.1.4 Test setup

The beams were tested under two point loading with simply supported end condition. Specimens are tested in a loading frame of 2000 kN (200 t) capacity with an effective span of 1100 mm. Load cell of 200 kN capacity with a least count of 1 kN is used to measure the applied load. The load is increased in stages till the failure of the specimen in the case of monotonic loading and at each stage of loading deflection at mid span is found out using a dial gauge. The test setup is shown in Fig.5. Following observations were made

1. First crack load
2. Displacement at mid span
3. Ultimate load
4. Crack pattern and failure mode

Figure 5: Test setup

5. Results and Discussion

The test result covers the fresh properties, mechanical properties and flexural properties of HFRGPC mix. The detailed investigation on the effect of hybrid fibre on the flexural behavior was carried out. The influence of hybrid fibre addition on the workability of GPC mix was studied by conducting the compacting factor test.

5.1 Test on workability of HFRGPC specimens

The influence of hybrid fibre addition on the workability of GPC mix was studied by conducting the compacting factor test. The test results are shown in Table 6

Table 6: Workability of HFRGPC specimens

Sl. No.	*Mix*	*Compacting*
1	GPC	0.99
2	SFRGPC	0.96
3	HFRGPC 1	0.94
4	HFRGPC 2	0.92
5	HFRGPC 3	0.89
6	HFRGPC 4	0.88

A. Test on hardened properties of HFRGPC specimens

Table 7: Summary on hardened properties of HFRGPC mixes

Mix designation	*Cube compressive strength (N/mm^2) 28 days*	*Flexural strength (N/mm^2) 28 days*	*Splitting tensile strength (N/mm^2) 28 days*
GPC	43.51	4.61	2.44
SFRGPC	51.24	6.84	3.84
HFRGPC 1	50.11	7.32	3.42
HFRGPC 2	48.16	7.48	3.02
HFRGPC 3	46.46	8.08	2.91
HFRGPC 4	40.39	8.02	2.80

The replacement of steel fibre with polypropylene fibre resulted in a decrease of compressive strength. But it is greater than normal GPC mix upto 30% replacement and after that it decrease below normal GPC mix. The addition of polypropylene fibre plays an important role in flexural strength. On the addition of polypropylene fibre, there was a considerable difference in flexural strength from 20% to 30%. As the percentage replacement increased from 30 to 40 there was a decrease in result. So the optimum replacement of steel fibre is fixed as 30% ie, 70% steel and 30% polypropylene fibre.

5.2 Test results on Beams

5.2.1 First crack load and ultimate load

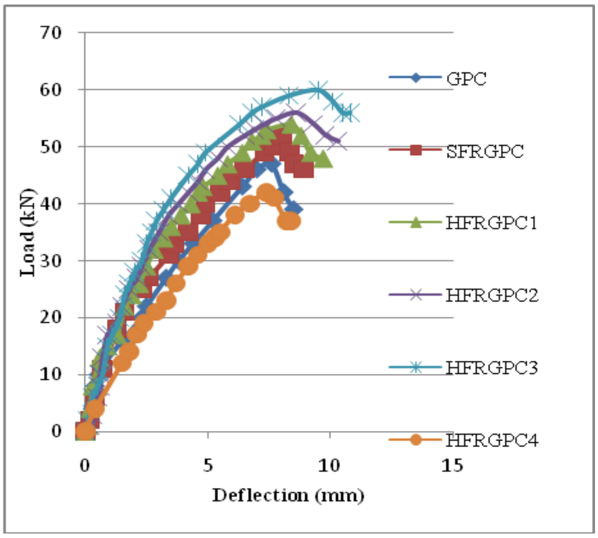
From the test results it can be seen that the addition of fibres increases the load carrying capacity for all the beams. The appearance of first crack was lower when compared to SFRGPC. But the ultimate flexural strength is higher for HFRGPC. This is due to the finer polypropylene fibres bridging the micro cracks more effectively than the steel fibres. The results of the first crack load and ultimate load for flexural beam specimens are tabulated in Table 8 and that for shear beam specimens are shown in Table 9.

Table 8: Test result for first crack load and ultimate load of flexural beam specimen

Sl. No	*Beam Designation*	*First Crack Load (kN)*	*Ultimate Load (kN)*	*Percentage gain of Ultimate Load*
1	GPC	20	47	-
2	SFRGPC	25	52	13.04
3	HFRGPC 1	24	54	17.39
4	HFRGPC 2	22	56	21.73
5	HFRGPC 3	20	60	30.43
6	HFRGPC 4	14	42	-8.69

5.2.2 Load deflection behavior

The recorded values of load and deflection were used to draw the load deflection plots. Mid span deflection was noted at every 2kN load increment. Deformation corresponding to each increment of load for all specimens was noted. The load deflection graph for all flexural specimen is shown in Fig 6



5.2.3 Energy absorption capacity

In general, the energy absorption capacity of a given material could be obtained from area under the load deflection plot of the specimen. Similarly toughness of the specimen can be measured using the load deflection curve obtained. Concrete will be effective in resisting the load until the formation of the first crack. At this stage concrete is relieved of its tensile stress and steel becomes effective at the cracked section. Energy absorbed at ultimate load can be obtained by calculating the area under load deflection curve upto the ultimate load.

Table 9: Energy absorption capacity

Beam Designation	*% Steel fibre*	*% Polypropylene fibre*	*Energy absorption Capacity(kNm)*
GPC	0	0	0.255
SFRGPC	100	0	0.303
HFRGPC1	90	10	0.371
HFRGPC2	80	20	0.421
HFRGPC3	70	30	0.478
HFRGPC4	60	40	0.221

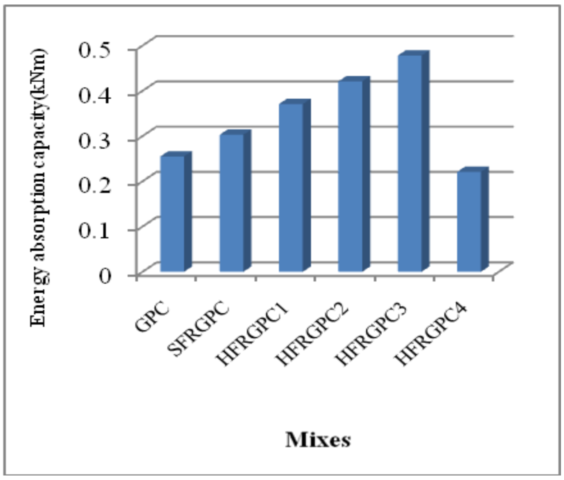


Figure 8: Energy absorption capacity for all flexural beam specimens

From the results it can be seen that energy absorption capacity was maximum for 30% replacement of steel fibre with polypropylene fibre.

5.2.4 Displacement ductility

The term ductilty in reinforced concrete beam may be defined as the ability of the beam to undergo large plastic deformation after the yielding of tensile reinforcement. An attempt was made in the present investigation to obtain the ductility factor for all the beams tested. The ductility factor is defined as the ratio of the ultimate deflection (δu) to the deflection at yield (δy). Due to inherent limitations of the testing machine, full load deflection curve could not be obtained. Therefore load deflection behaviour up to 90 % of peak load was noted. Displacement ductility was calculated as the ratio of deflection at yield load and deflection at 90% peak load.

Table 10: Deflection ductility of beam specimens

Beam Designation	*% Steel fibre*	*% Polypropylene fibre*	*Displacement Ductility factor*
GPC	0	0	1.875
SFRGPC	100	0	1.956
HFRGPC1	90	10	2.96
HFRGPC2	80	20	3.234
HFRGPC3	70	30	4.452
HFRGPC4	60	40	4.195

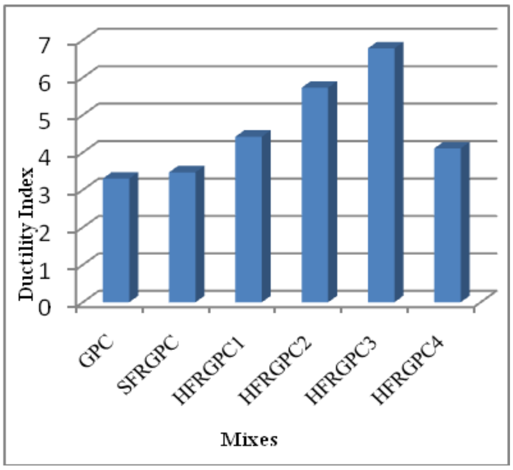


Figure 10: Displacement ductility factor for all flexural specimens

6. Conclusion and Scope

A. *Conclusion*

Based on the experimental results, the following conclusions are drawn:

- GPC mix i.e. geopolymer concrete without fibres showed maximum workability. The workability of concrete had been found to decrease with increase of fibre content in concrete. It might be due to viscous nature of geopolymer concrete and uneven distribution of fibres in the mix.
- Addition of steel fibres increases the split tensile strength. The increase was significant for mix with 0.5% steel fibre.
- Addition of steel fibre increased the flexural strength of concrete. The optimum mix percentage obtained was for 0.50% steel by volume. Thereafter there is no remarkable increase in flexural due to decreased workability and lumping of fibres.
- Compressive strength of HFRGPC increases upto 30% replacement of steel fibre with polypropylene and then decreases. Hence the optimum replacement percentage of steel fibre is 30% by volume.
- Hybrid fibre reinforced concrete showed an increase in flexural strength. The appearance of first crack was lower when compared to SFRGPC. But the ultimate flexural strength is higher for HFRGPC. This is due to the finer polypropylene fibres bridging the micro cracks more effectively than the steel fibres.

B. *Scope*

- The work can be extended by changing type of fibre.
- Study shear behavior of FRGPC beams for various shear span to depth ratios.
- Study the flexural behavior of FRGPC beams for various reinforcement ratios and various cover.

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