Mechanical Properties and Behaviour of Hybrid Fibre Reinforced Geopolymer Concrete Columns under Ambient Curing

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***Abstract:*-The environmental problems caused by cement production can be reduced by finding an alternative material. One of the potential materials to substitute conventional concrete is geopolymer concrete. Geopolymer concrete is an inorganic alumino-silicate polymer synthesized from predominantly silicon, aluminum and by-product materials such as fly ash. Utilization of fly ash and Ground Granulated Blast Slag as an alternative material in concrete reduces the use of OPC in concrete. Evolution of geopolymer concrete cured at ambient temperature broadens its suitability and applicability to concrete based structures. The steel fibres are added at varying percentages of 0, 0.25, 0.5, 0.75 and 1.After getting the optimum percentage of steel fibres, the polypropylene fibre are varied at 0, 10, 20, 30 and 40 percentages of steel fibre with optimum steel fibre remains constant. For curing, temperature was fixed at room temperature for 24 hours. The specimens are tested after the ages of 7 and 28 days. The concrete specimens were tested for mechanical properties of concrete namely, cube compressive strength, splitting tensile strength, and other test were conducted for cement, chemical admixture, and coarse aggregate & fine aggregate. The impact of steel fibres and hybrid polypropylene- steel fibres on the load - deflection behaviour, first crack load, ultimate load and energy absorption capacity of concrete columns are studied in this work.**

Keywords: Polypropylene Fibre,Geopolymer

I. INTRODUCTION

The applications of concrete in the area of infrastructure, habitation, and transportation have greatly prompted the development of civilization, economic progress, and stability and of the quality of life. However, due to raw materials, some inherent disadvantages of Portland cement are still difficult to overcome. There are two major drawbacks with respect to sustainability. About 1.5 tonnes of raw materials is needed in the production of every tonne of Portland cement, at the same time about one tonne of carbon dioxide (CO2) is released into the environment during the production. Another effort to make environmental 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. It was found that heat-cured low-calcium fly ash-based geopolymer concrete possesses high compressive strength, undergoes very little drying shrinkage and moderately low creep.

Geopolymer:- It is an inorganic alumina-silicate polymer is synthesized from predominantly silicon and aluminium material of geological origin or by-product materials such as fly ash, ground granulated blast slag (GGBS). Ground Granulated Blast Slag was replaced in different proportions to fly ash to enhance various properties of concrete Geopolymer concrete do not require any water for matrix bonding, instead the alkaline solution react with Silicon and Aluminium present in the fly ash Geopolymer is synthesized by mixing alumino silicate-reactive material with strong alkali solutions, such as sodium hydroxide (NaOH) or potassium hydroxide (KOH), sodium silicate or potassium silicate. The mixture can be cured at room temperature or temperature cured. The GPC was found to have a high degree of durability when it had inorganic binder based on alumina and silica containing materials like fly ash and GGBS. But, as in conventional reinforced concretes, the GPC also needs to be reinforced with steel bars for its large scale utility in civil engineering structural applications. Hence, the investigations on behaviour of Reinforced GPC (RGPC) were undertaken.

The objectives of the work can be summarized as

- To develop the proper mix proportion for geopolymer concrete and steel fibre reinforced geopolymer concrete.
- To study the load - deflection behaviour of concrete columns
- To obtain the first crack load and ultimate strength concrete mix at various fibre content.
- Comparison of results of geopolymer concrete specimens with hybrid geopolymer concrete specimens.

II. EXPERIMENTAL INVESTIGATION

The main objective of the study is to investigate the impact of steel fibres and hybrid polypropylene-steel fibres on the mechanical properties and ultimate strength of geopolymer concrete under ambient curing condition. The experimental programme consisting of casting and testing of steel fibre reinforced geopolymer concrete specimen and hybrid fibre reinforced geopolymer concrete specimen, to study their mechanical properties.

A. Test On Constituent Materials

Flyash:-Low-calcium, Class F, obtained from the silos of Mettur Thermal Power Plant in Tamil Nadu. It is refractory and alkaline in nature, having fineness 2.98 and specific gravity 2.36

Ground Granulated Blast Furnace Slag:-Different laboratory tests were conducted on GGBS to determine Fineness, Specific Gravity. The specific gravity is 3.21 and fineness 2.78.The results conforms to the IS recommendations.

Fine Aggregate:- M sand is to be used as fine aggregate. It is to be used at the Saturated and Surface Dried (SSD) condition. M sand passing through 4.75mm IS sieve conforming to grading zone II of IS 383:1970 was used. Its specific gravity is 2.456.

Coarse aggregate:-Coarse aggregate of maximum size 20 mm from local source was used. The specific gravity is 2.82 and fineness modulus 6.7

Crimped steel Fibres:- Crimped steel Fibres from lathe industry was used.The long fibres were cut to approximately 30mm length,0.5mm dia and aspect ratio 60were used for the study. before using in the mix.Fig shows the steel fibres used for the study

Fig 1:Steel Fibre

Polypropylene fibres:-Fibres of Virgin Polypropylene Homo-Polymer of length 12mm was used for the study.

Fig 2: Polypropylene Fibre

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 pellets in water. The degree of purity of the pellets was 97% and was taken into account to modify the quantities. Distilled water was used to dissolve the pellets to avoid affecting the solution by tap water contaminations.

Adding soluble silica has been shown to have positive effects on the properties and strength of geopolymers. It is also believed that using sodium silicate along with sodium hydroxide, enhances the formation of geopolymers.

Fig 3 Sodium Hydroxide flakes

Fig. 4 Sodium silicate solution

Superplasticiser:-In order to achieve the desired workability, a naphthalene based superplasticizer was used as the water reducer. In this project Conplast SP-430 was used as superplasticizer. The dosage of super plasticizer used was 2% of fly ash. It is brown in colour

Fig: 5 Conplast

Reinforcement:- High Yield Strength Deformed Steel bars of 6 mm and 8 mm diameter were used for the study. 8 mm bars were used as longitudinal reinforcement and 6 mm bars were used for lateral ties. The pitch of the stirrups was 125 mm.

Water:-Potable water is generally considered as being acceptable. Hence water available in the college water supply system was used for casting as well as curing of the test specimens.

III. PRELIMINARY EXPERIMENTAL INVESTIGATION

This work was done to find the optimum percentage of steel fibre

A. Mix Design

So far no standard mix design approaches are available for GPCs, since they are a new class of construction materials. So trial and error method is adopted. To arrive the mix proportion for the present study, the optimum values of different parameters were adopted from previous literature.
The previous results shows that the compressive strength of fly ash-based geopolymer concrete increases with the increases in curing temperature in the range of 60ºC to 90ºC.But in the present study inorder to keep ambient curing condition, since it is most economical, an optimum replacement of 50% GGBS in flyash was adopted which give better result.
From previous researches it was found that consistent results were gained upon keeping the alkaline solution at a sodium silicate to sodium hydroxide ratio of 2.5. This ratio was favoured over a lesser one because of the reliable results that it yielded, and because the sodium silicate solution is considerably cheaper than the sodium hydroxide pellets. So for present study, sodium silicate to sodium hydroxide ratio fixed as 2.5.
Earlier studies discovered that specimens cured under ambient conditions exhibited significant 28thday compressive strength. From the previous literatures the optimum values taken as, alkaline liquid to fly ash ratio is 0.7 and fine aggregate to total aggregate ratio was 0.3. In the design of geopolymer concrete mix, coarse and fine aggregates together were taken as 77% of entire mixture by mass. From the past literatures it is clear that the average density of fly ash-based geopolymer concrete is similar to that of OPC concrete (2400 kg/m^3). Knowing the density of concrete, the combined mass of alkaline liquid and fly ash can be arrived at. By assuming the ratios of alkaline liquid tofly ash as 0.35, mass of fly ash and mass of alkaline liquid was found out.

To obtain mass of sodium hydroxide and sodium silicate solutions, the ratio of sodium silicate solution to sodium hydroxide solution was fixed as 2.5. For the present investigation, concentration of NaOH solution is taken as 14 M. The dosage of super plasticizer was 2% fly ash. Extra water (other than the water used for the preparation of alkaline solutions) added to the mix according to the workability desired

TABLE 1 MIX DESIGNATION FOR DIFFERENT MIXES

Designation	Fly ash (%)	GGBS (%)	Steel Fibre (%)
GPC	50	50	0
SFRGPC1	50	50	0.1
SFRGPC2	50	50	0.25
SFRGPC3	50	50	0.50
SFRGPC4	50	50	0.75

TABLE 2 QUANTITIES OF INGREDIENTS USED FOR MIX PROPORTIONS

Particulars	Quantity (kg/m^3)
Flyash	550
GGBS	200
Fine aggregate	550
Coarse aggregate	1250
NaOH	16
Na_2SiO_3	95
Water	50

A. Specimen details

cubes of size 150mm x150mm x 150mm for compressive strength test, cylinders of 150mm diameter and 300 mm height for splitting tensile strength test,beams of size 500mm x100mm x100 mm for flexural strength test were cast.

TABLE 3 SPECIMEN DETAILS

Mix Designation	Cube	Cylinder	Beam
GPC	6	3	3
SFRGPC1	6	3	3
SFRGPC2	6	3	3
SFRGPC3	6	3	3
SFRGPC4	6	3	3
TOTAL	30	18	18

TABLE 4: SUMMARY OF HARDENED PROPERTIES OF CONCRETE

Mix designation	56th day Cube compressive strength ((N/mm^2)	28th day Cube compressive strength ((N/mm^2)	Splitting tensile strength (N/mm^2)	Flexural strength (N/mm^2)
GPC	45.81	40.15	2.46	4.9
SFRGPC1	46.82	42.95	2.86	5.4
SFRGPC2	48.43	44.16	3.27	5.7
SFRGPC3	53.46	49.84	3.95	6.3
SFRGPC4	55.71	51.12	4.1	6.6

From this the optimum is choosen as SFRGPC3 ie, Optimum fibres taken as 0.5% as further increase resulted in poor workability.

IV. EXPERIMENTAL INVESTIGATION ON COLUMNS

The present study aims to examine the deflection and energy absorption capacity of steel fibre reinforced geopolymer concrete columns. The effects of fibres in improving deflection, cracking behaviour, ductility factor and energy absorption capacity of HFRGPC columns were also studied. In this, steel fibre ie, 0.5% of total volume which is obtained as optimum in previous chapter is constant and polypropylene fibre is varied as 10,20,30,40 and 50% of steel fibre.

A. Mix design for hybrid fibre reinforced geopolymer concrete (HFRGPC)

Hybrid fibre reinforced geopolymer concrete (HFRGPC) was obtained by adding optimum steel fibre which is obtained as 0.5% of total volume and polypropylene fibre in different proportions of steel fibre as 10 to 40%, on to GPC. Crimped steel fibres having diameter 0.50 mm and length 25 mm (aspect ratio 50) and polypropylene fibres of 12 mm length were used.

B. specimen details

From each mix, 30 cubes of size 150 mm x150 mm x150 mm to determine the compressive strength, 18 cylinders of size 150mm diameter and 300mm height to determine splitting tensile strength and 12 beams of size 500mmx100mmx100mm to determine the flexural strength were also cast in addition to columns.

TABLE 5 MIX DESIGNATIONS FOR DIFFERENT MIXES

Sl.No.	Mix Designation	Mix Details
1	GPC	Control Mix1
2	SFRGPC3	Control Mix2
3	HFRGPC1	0.5% steel fibre and polypropylene fibre in 10% of steel fibre
4	HFRGPC2	0.5% steel fibre and polypropylene fibre in 20% of steel fibre
5	HFRGPC3	0.5% steel fibre and polypropylene fibre in 30% of steel fibre
6	HFRGPC4	0.5% steel fibre and polypropylene fibre in 40% of steel fibre

TABLE 6 SPECIMEN DETAILS

Mix Designation	Cube	Cylinder	Beam
GPC	6	3	3
SFRGPC3	6	3	3
HFRGPC1	6	6	3
HFRGPC2	6	3	3
HFRGPC3	6	3	3
HFRGPC4	6	3	3
TOTAL	30	18	18

C. Preparation and casting of specimens

For each mix six concrete cubes of size 150x150x150mm for compressive strength test, three cylinders of 150mm diameter and 300mm height for splitting tensile strength test and three beams of 500x100x100 for flexural strength test were casted.

To study the load deflection behaviour 12 column specimens of 150 mm breadth, 150 mm depth and 1000 mm length were casted. For each type, two reinforced columns of size 1000x150x150mm were casted.

D .Tests on specimens

Testing of concrete specimens plays an important role in controlling and confirming the quality of concrete. All the specimens cast were subjected to testing in order to study the effect of replacement of cement with constant amount of flyash and GGBS in the geopolymer concrete at ambient temperature on workability, strength and load deflection behaviour. Thus the experimental investigation carried out was divided in to three main headings. They are as follows:

1. Study on workability
- Compacting factor test

2. Study on strength
- Compressive strength test
- Splitting tensile strength test
- Flexural strength test

3. Study on Properties of column

E. Test setup

The testing was carried out in the loading frame and the compressive load was applied with the hydraulic loading jack of capacity of 1000kN. 50 tonne load cell with load indicator was used for measurement of load applied on the column. Concentric compressive load was applied on all the specimens. Lateral deflections were measured at mid height using a dial gauge. Axial deformations were measured using a dial gauge which was fixed on to the moving base of the hydraulic jack.

Fig: 6 Test Setup

V. RESULTS AND DISCUSSIONS

The study on fresh properties of concrete, mechanical properties of concrete, Study of the effect of fibres in improving deflection, cracking behaviour, ductility factor, energy absorption capacity of GPC, SFRGPC3 and HFRGPC column are also discussed in this chapter.

A. Test On Fresh Properties Of Concrete

The values obtained are shown in Table 5.1. It was found that the value of fresh properties goes on changing with the addition of fibres. As the percentage of polypropylene increases, the fresh properties go on decreasing.

TABLE 7.COMPACTING FACTOR

Sl. No	Mixes	Compacting Factor
1	GPC	0.97
2	SFRGPC3	0.9
3	HFRGPC1	0.88
4	HFRGPC2	0.85
5	HFRGPC3	0.8
6	HFRGPC4	0.79

B. Cube Compressive Strength

Compressive strength of all concrete mixes was determined at 28 and 56 days of curing. Comparing to GPC, HFRGPC2 has showed an increase in strength of 40% at 28 days and 37% at 56 days. Comparing to SFRGPC3, HFRGPC3 has showed an increase in strength of 20% at 28 daysand 24% at 56 days. From the compressive strength test, HFRGPC3 was obtained as the optimum percentage

C. Splitting Tensile Strength

The test results are given in Table 5.3.. Percentage increase in strength of HFRGPC3 was 70% when compared to GPC and 7% compared to SFRGPC3

TABLE 8 COMPRESSIVE STRENGTH OF CONCRETE

Sl. No	Mixes	Average compressive strength (N/mm^2)	
		28 days	56 days
1	GPC	40.15	45.81
2	SFRSPC3	47.16	51.43
3	HFRGPC1	51.2	58.76
4	HFRGPC2	56.4	62.81
5	HFRGPC3	58.72	64.15
6	HFRGPC4	55.4	61.75

TABLE 9 SPLITTING TENSILE STRENGTH

Sl. No	Mixes	Average Splitting Tensile Strength (N/mm^2)
1	GPC	2.46
2	SFRGPC3	3.9
3	HFRGPC1	4
4	HFRGPC2	4.2
5	HFRGPC3	4.1
6	HFRGPC4	4

D. Flexural Strength

Percentage increase in strength of HFRGPC3 was 42% when compared to GPC and23 % compared to SFRGPC

TABLE 10 FLEXURAL STRENGTH

Sl. No	Mixes	Average Flexural Strength (N/mm^2)
1	GPC	4.9
2	SFRGPC3	5.7
3	HFRGPC1	6.2
4	HFRGPC2	6.6
5	HFRGPC3	7
6	HFRGPC4	6.8

E.Test Results On Column

a. Load - Deflection Behaviour

The deflection of the column in each increment of load was measured. The load deflection curves for axial displacement and lateral displacement for all the specimens are shown in Fig 6.4 and Fig 6.5. The compressive load carrying capacity of the columns increases with increase in fibre content. It may be seen that ultimate load carrying capacity of HFRGPC3 columns increased much more than GPC and SFRGPC3 columns. This increase in ultimate load may be because of the fibres intercepting the cracks and preventing their prorogation resulting in higher load carrying capacity. Also, with the addition of fibres, the cracks developed in the columns get arrested

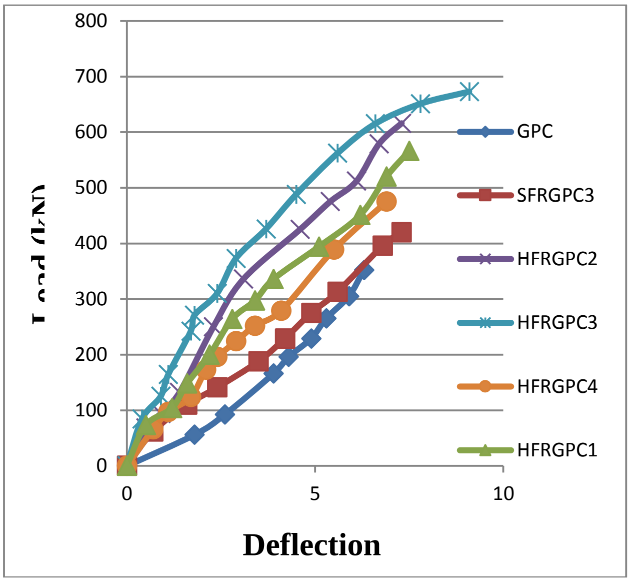

Fig:7 Axial load deflection curve

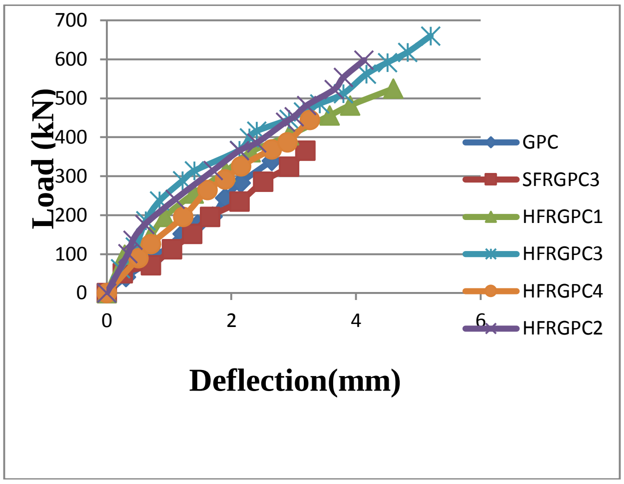

Fig: 8 Axial load deflection curve

b. Displacement Ductility

Ductility refers to the ability of structural members to withstand large deformation after the yielding of tensile reinforcement. The ductility of structural members is the major consideration in earthquake regions.

Ductility factor, $\Psi = du/dy$,
Where du= Displacement at ultimate load
dy= Displacement at yield load

TABLE 11 COMPARISON OF DUCTILITY FACTOR

Column Designation	Ultimate Load (kN)	Yield Load (kN)	Displacement at yield Load (mm)	Displacement at Ultimate Load (mm)	Ductility factor
GPC	340	220	1.71	3.8	2.22
SFRGPC	366	240	1.89	3.9	2.06
HFRGPC1	525	305	1.9	4.6	2.46
HFRGPC2	598	325	1.98	4.9	2.47
HFRGPC3	660	340	2	5.2	2.6
HFRGPC4	445	300	2.1	4.15	2.3

C .Energy Absorption Capacity

The energy absorption capacity could be obtained from the area under the load deflection plot. Due to sudden shear failure full load deflection plot could not be obtained. Therefore area up to peak load was taken to compare the energy absorption capacities as shown in Table 12. The energy absorption capacity is maximum for HFRGPC3.

TABLE 12 ENERGY ABSORPTION CAPACITY

Mixes	Energy absorption capacity
GPC	441.04
SFRGPC3	577.03
HFRGPC1	1510.235
HFRGPC2	1413.97
HFRGPC3	2078.195
HFRGPC4	791.02

Fig shows the failure pattern of cracked GPC column.All the column failed due to crushing of concrete. With the addition of fibre, the propagation of cracks get arrested.

Fig 9 GPC column after testing

Fig 10 HFRGPC3 column after testing

VI. CONCLUSION

An experimental investigation was carried out to study the behavior of geopolymer concrete columns and also the effect of steel fibres and polypropylene fibres on the compressive constitutive behaviour of these s columns. A total of 12 columns were cast and tested for present investigation for a total of six mixes. There were 2 columns from each mix, one was standard GPC mix, second one was SFRGPC3 which was taken as the optimum for steel fibre reinforced geopolymer concrete, based on the compressive strength. The next four mixes were hybrid fibre reinforced geopolymer concrete with varying percentage of polypropylene fibre. The major conclusions drawn from the experimental investigation were

- When fibre is added to concrete, the mix becomes stiff. So the workability is decreased with addition of fibre. The workability can be improved by adding super plasticizer to some extent.
- In the case of SFRGPC mixes, the mix obtained by the addition of steel fibre in 0.5% of total volume was taken as the optimum mix
- When fibres are added to concrete, crack propagation is arrested and this results in improving load carrying capacity and energy absorption capacity

- There is an increase in early age compressive strength due to the addition of fibre in concrete. Comparing to GPC, HFRGPC3 has showed an increase in strength of 40% at 28 days and 37% at 56 days. Comparing to SFRGPC3, HFRGPC3 has showed an increase in strength of 20% at 28 days and 24% at 56 days.
- The energy absorption capacity and ductility of HFRGPC columns were also more than normal GPC columns, which is an important point for seismic design application where the structure should be capable of sustaining large deformation without collapse.
- Similarly the ductile factor of columns with steel fibre and polypropylene fibre is also more than normal GPC.
- Percentage increase in splitting tensile strength of HFRGPC3 was 70% when compared to GPC and 7% compared to SFRGPC3.
- Percentage increase in flexural strength of HFRGPC3 was 49 % when compared to GPC and 23% compared to SFRGPC3

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