A Study on Hybrid Fiber Reinforced Geopolymer Concrete Short Columns Under Uni-Axial Compression

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ABSTRACT

The existing literature is rich in plain cement concrete short columns, but it is deficient with respect to geopolymer concrete (GPC) short columns with the incorporation of fibers with hybridization. The current investigation focuses to identify and measure the structural performance and behavior of two grades of GPC viz., normal and high strength grade with and without hybrid fibers. Two types of fibers i.e., steel and polypropylene are utilized to prepare the hybrid fiber reinforced GPC(HFRGPC) ranging from 0-2% in the increments of 0.5% coupled with longitudinal reinforcement. A total of 20 short columns (10 circular and 10 square headed) having a height of 1000 mm and sizes of 150 mm dia. and 150x150 mm respectively are prepared and tested for uni axial compression loading. The study results indicated that the circular GPC short columns possess better structural performance at ultimate load in terms of ductility ratio than those of square headed GPC specimens with and without fibers. The significant impacts of fiber volume fraction are investigated and reported. The experimental results of the of short columnsshowed a good agreement with the theoretical results.

Keywords: Axial Strength,GeopolymerConcrete,HybridFibers,Structural Performance

1.0 Introduction

With an anticipated yearly consumption of 30 billion tones, concrete is widely employed as a significant building materials for building infrastructure (Firdous et al., 2022). Concrete is traditionally made using ordinary Portland cement (OPC) as the binding ingredient. Therefore, the preparation of a large amount of OPC is a significant industrial activity that accounts for 6-8% of CO_2 in the total emissions of greenhouse gases (Monteiro JandRoussanaly,2022).Instead of cement, aluminosilicate binders are used to generate a new form of concrete called geopolymer concrete. Making geopolymer concrete involves geopolymerizing high-alumina and silica basedindustry exhausts.Class F Fly ash and GGBS are the two industrial by-products that are utilized as binders. To improve the mechanical, chemical, and physical qualities of concrete, these industrial byproducts are utilized in part place of cement. Many research projects have looked into using industrial byproducts in concrete instead of 100% cement in recent years. Significant reductions in CO_2 emissions will result from the complete substitution of cement with industrial byproducts(Davidovits,1991).Two commercially accessible binders FA and GGBSare synthesized to form GPC along with alkaline solutions. Investigations revealed that the preparation of paste and concrete based on geopolymers significantly reduces greenhouse gas emissions (Farhan et al.,2018 ; Kashyap et al., 2018; Mallinadh et al.,2020). Numerous studies have demonstrated the strength and mechanicalcharacteristics of GPC, which are equivalent to cement concrete. However, employing geopolymer concrete has certain disadvantages, including the need for specialized handling, expensive alkaline solution costs, and mix homogeneity loss. Although less ductile than OPC concrete, geopolymer concrete offers higher fire resistance and is less prone to creep and shrinkage. Additionally, geopolymer concrete possesses chemical resistance to chloride and sulphate assaults that is equal to or even greater than that of OPC concrete when compared to OPC concrete. Early research reveals that geopolymer concrete's compressive strength is significantly increased by heat curingaa(Monteiro andRoussanal, 2022). However, due to heat curing, geopolymer concrete cannot be used for precast elements. Ambient-cured geopolymer concrete development, which simplifies and provides affordable solutions for in-situ constructions, represents a significant new development in geopolymer concrete application. Geopolymer construction materials work well for prefabricated buildings. Few investigations have been done on the structural elements of GPC, but many have been done on the mechanical properties and durability traits of the material. There hasn't been much research done on how ambient-cured geopolymer concrete behaves (McLellan et al., 2011 ; Kashyap et al., 2021 ; Sujatha et al., 2012). Twelve geopolymer concrete columns with cross sections of 175 mm and heights of 1500 mm are examined. They are reinforced with steel bars. Theoretical conclusions drawn from the study's test results were in agreement with Australian Standard AS 3600-01 (AS)2001) and American Design Code ACI 318-02. (ACI 2002) calculations (Sumajouw et al., 2007). The analytical approach for OPC concrete columns may be used to study steel-RC geopolymer concrete columns that have a satisfactory stress-strain relationship (Sarker P.K,2009).Circular RCC and GPC columns with the blending of steel and PP fibers are tested for uni axial compression. Steel fiber insertion was proven to significantly increase the columns' deformability. Additionally, during uniaxial compression, the capacity of short columns and ductility aspect were higher at 1.5% Steel fiberand 0.5% Polypropylene fibercombination than other percentages (Turner, and Collins; 2013)

In this study the mechanical properties and strength of short GPC columns with different cross-sections and varying percentages of hybrid fibers under uni-axial compressive stress.

2.0Experimentation

2.1 Details of Test Matrix

The two different kinds of ingredients utilized to prepareGPC. Class F fly ash with norms for its physical and chemical composition as per ASTM C618 F and GGBS with ASTM C 1697-16 requirementsare used.River sand was utilized as a filler ingredient to close the gaps, and standard grade geopolymer concrete was made using graded coarse aggregate in the sizes 20, 12, and 6 mm. The aggregates' physical properties comply with IS:2386-1963 (Reaffirmed 2002). The results of the tests show that the aggregates meet the requirements of zone II of IS: 383-1978. (Reaffirmed 2002). Table 1 displays the pozzolanic materials' oxide content, and the two aggregates' specific gravities are 2.65 and 2.86, respectively. A local source provides NaOH pellets with a purity of 97-98%, which are then dissolved in distilled water to create a 12M concentration of NaOH. Na_2SiO_3, sometimes known as water glass, is another alkaline activator solution utilized in the preparation of GPC. The chemical composition for Na_2SiO_3 is Na_2O=14.6%, SiO_2=29.5%, and H_2O=55.8% by mass. The ratio of Na_2SiO_3/NaOH was 2.5 is adopted. A chemical ingredient called CONPLAST SP 430 is used to make geopolymer concrete more workable.

Table-1: Oxide composition in F-FA and GGBS

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O
Class F-FA	66.80	24.50	4	1.50	0.45	0.40
GGBS	39.18	10.18	2.02	32.82	8.52	1.1

2.1Design of Mix

The following are ingredients were used in the M30 and M70 GPC mixes furnished in Table.2

Table 2: Mix Ingredients of GPC concrete

S.No.	Constituents	M30 grade Quantity(kg/m^3)		M70 grade Quantity(kg/m^3)	
1.	Binder (FA+GGBS) (50%+50%)	360		410.70	
2.	Na_2SiO_3	70.8		117.30	
3.	NaOH	28.3		47	
4.	SP (1.5%)	5.4		6.16	
5.	Fine aggregate	798		770	
6.	Coarse aggregate	882	20mm----529.2Kg 12mm----264.6Kg 6mm ------88.2Kg	1155	20mm----693.0Kg 12mm----346.5Kg 6mm ------115.5Kg
7.	Steel+PP fibres	(0.5%+0.5%)	3.6	(0.5%+0.5%)	4.10
		(1%+0.5%)	5.4	(1%+0.5%)	6.16
		(1.5%+0.5%)	7.2	(1.5%+0.5%)	8.21

The aggregates are dry-mixed in a pan mixer for the first two minutes. The produced alkaline initiator solution and SP are then mixed for three minutes, or until the combination is homogeneous, with the blended binder, aggregates, and SP. The mixture is then gradually supplemented with steel(SF) and polypropylene(PP) fibers to achieve the ideal distribution of fibers without the risk of balling. To determine the necessary workability condition for structural elements in accordance with the criteria of the IS code, the slump cone test is performed for all mix proportions. The purpose of casting the cube, cylinder, and prism specimens is to evaluate their mechanical qualities. The fiber for hybrid fiber geopolymer matrices is made of polypropylene (PP) fiber and hooked end steel.The study uses steel fiber with an aspect ratio of 60, length 30 mm, and a diameter 0.5 mm, together with PP of length 12 mm, 1050 deniers. The GPC specimens are cast for one day, demolded, and then cured for 28 days in an ambient environment. In Figure.1, the cast and cured specimens are displayed. The characteristics of mechanical strength and workability are listed in Table 3.

2.2 Methodology

The current experimental inquiry was divided into two stages. The first stage of the study involves the developing M30 and M70 grade geopolymer concrete, and the evaluation of the mechanical characteristics of concretes. In the second part of the programme, geopolymer columns are cast in two distinct geometries (circular and square) keeping constant main rebar reinforcement ratio with and without hybrid fibers, and they are then assessed under uni-axial stress.

The compressive, tensile, and flexural strengths of concrete are determined in the first part of the investigation using cube specimens of 150 x 150 x 150 mm, cylinder specimens measuring 300 mm x 150 mm, and beam specimens measuring 700 x 100 x 100 mm in size. The specimens are taken out of their respective molds, kept for 28 days for curing (ambient environment).The cube specimens are tested under Compression Testing Machine (100 T) andremainingona universal testing machine (40T).

Table 3: Workability and Mechanical Characteristics of GPC mixes

S.No	Mix Specification	% of fiber content (Steel+PP)		Slump (mm)	Compressive strength (MPa)	Split-tensile strength (MPa)	Flexural strength (MPa)
1.	M30 GPCF0- CM - M1	0	0	115	38.62	2.64	3.2
2.	M30 GPCF0.5-M2	0.25	0.25	111	39.53	3.12	3.9
3.	M30GPCF 1 – M3	0.5	0.5	108	41.8	3.70	4.2
4.	M30 GPCF1.5 – M4	1	0.5	100	44.8	4.32	4.8
5.	M30 GPCF2 – M5	1.5	0.5	92	41.86	4.10	3.84
6.	M70GPCF0-CM– M6	0	0	82	72.87	5.52	6
7.	M70GPCF0.5-M7	0.25	0.25	76	79.82	5.98	7.2
8.	M70GPCF 1 – M8	0.5	0.5	68	82.63	6.51	8.52
9.	M70GPCF 1.5 – M9	1	0.5	56	84.37	6.92	9.3
10.	M70GPCF 2 –M10	1.5	0.5	50	83.65	6.8	9

Fig.1 GPC Cast Specimens

Fig.2 Specimens under Compression, Split-tensile and Flexural Strength Tests

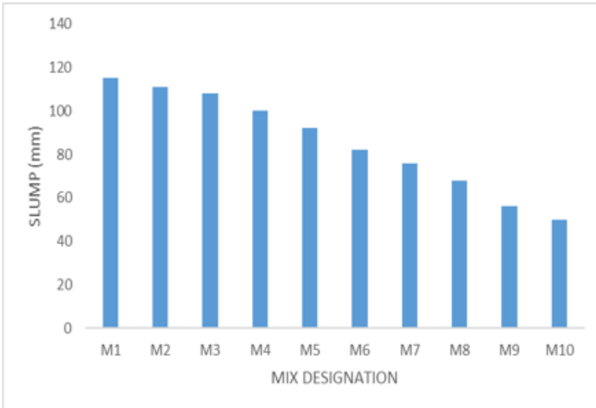

Fig.3 Slump values for different mixes

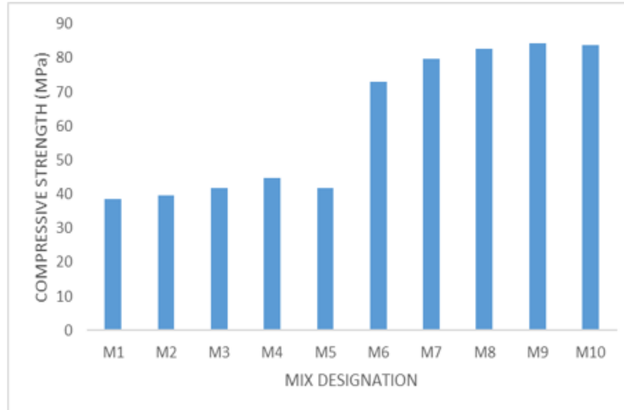

Fig.4 Compressive Strength for different mixes

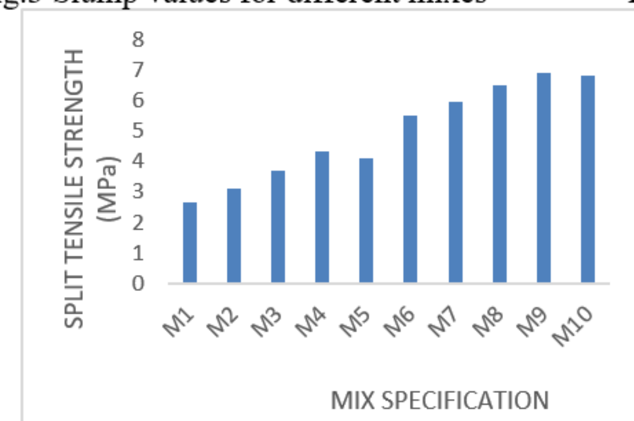

Fig.5 Split-tensile strength for different mixes

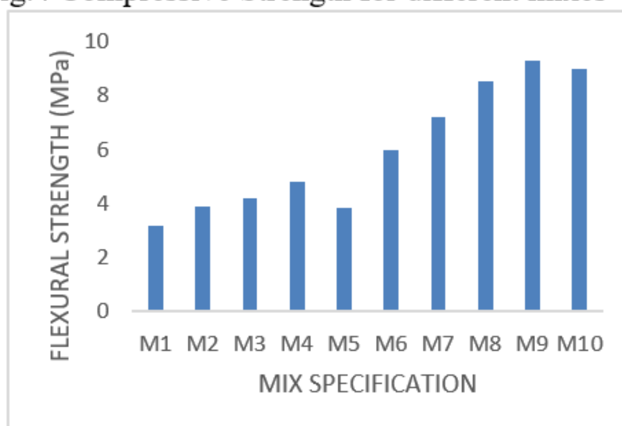

Fig.6 Flexural Strength for different mixes.

According to Table.3and fig.3, the amount of fiber in concrete has an indirect relationship with workability since fiber makes fresh concrete harsh, which changes the slump value. A GPC mix containing 1.5 percent fiber fractions is used to study the strength and behavior of two grades of GPC. The mechanical characteristics of the M4 and M9 mixes are superior to that of other fiber mix proportions.

In the second stage of the investigation, GPC short columns with square cross sections of 150x150 mm with tapered heads measuring 230mmx230 mm and an overall height of 1000 mm and circular specimens with 150 mm diameter cross section with tapered heads of 230 mm dia., 100 mm depth and an overall height of 1000 mm are prepared for the experimental study. 4-12mm diameter and 6-10mm diameter bars are used as longitudinal reinforcement for square and circular columns respectively. As transverse reinforcement 6mm dia. bars with

100mm c/c spacing are used for these two types.The typical diagrams of the column specimens are furnished in Fig.7-8. The cast and test model specimens are furnished in Fig.9-14.

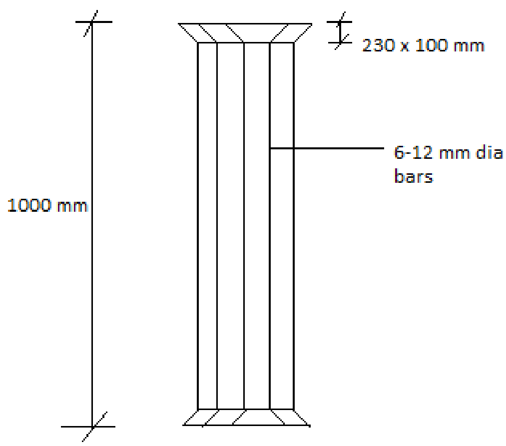

Fig.7 Sectional details of circular column

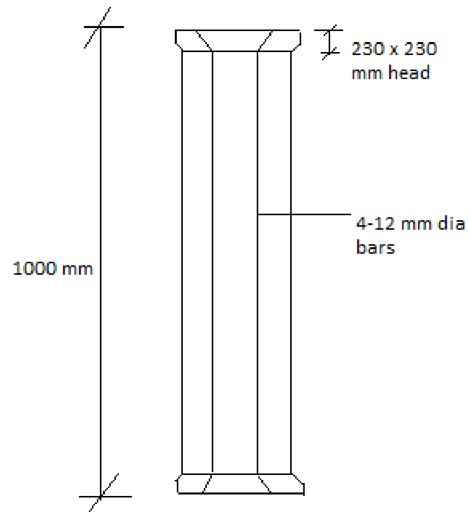

Fig.8 Sectional details of square column

Fig.9 Square and Circular Head Reinforcement CagesFig.10 Test Setup Arrangement

Fig.11 Failure of M30 GPC model specimens without fibers Fig.12 Failure of M30 GPC model specimens with hybrid fibers

Fig.13 Failure of M70 GPC model specimens without fibers   Fig.14 Failure of M70 GPC model specimens with fibers

2.3 Behavior of Short columns under axial compression

According to IS: 456-2000 for short columns, the governing theoretical differential equation equation for axially loaded short columns assumes concrete and steel have design strengths of 0.4 f_{ck} and 0.67 f_y, respectively. Then the ultimate load equation is

$$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc} \text{ .... } (1)$$

In this investigation, the characteristic compression strength of GPC (f_{ck}) is replaced with compression strength of GPC by considering the influence of hybrid fibers and is denoted by f^1_{ck}in the above eq.(1)

2.3.1Empirical Equation to predict Compressive Strength of fiber reinforced GPC

The above equation (1) is valid for short columns with plain concrete and longitudinal reinforcement only. A formula is suggested to forecast compressive strength of fibre reinforced GPC and the proposed equation is fit for both normal and high strength grade concretes. Replacing fck by f^1_{ck} value in equation(1), the modified equation can be extended to fibre reinforced short columns for predicting its ultimate load carrying capacity.

$$f^1_{ck} = f_{ck} + 1.75(\sqrt{f_{ck}})v_f \text{ .... } (2)$$

where,

f^1_{ck} = compressive strength of GPC with the influence of fibers

f_{ck} = characteristic compressive strength of GPC;v_f= percentage of hybrid fibers by volume

The proposed equation is suitable for 0-2% percentage of hybrid fibers by volume

Table 4: Experimental results of M30 grade GPC short columns

Column Specification	% of fibers		Ultimate load (P_u)exp kN	Theoretical Load P_u (kN)	Reserve Strength (Exp) (%)
	SF	PP			
30GPCCF0	0	0	474.44	398.0	0
30GPCCF0.5	0.25	0.25	482.53	442.4	1.7
30GPCCF1	0.5	0.5	502.71	486.9	5.95
30GPCCF1.5	1	0.5	529.38	527.0	11.6
30GPCCF2	1.5	0.5	503.24	566.8	6.07
30GPCSF0	0	0	466.39	390.5	0
30GPCSF0.5	0.25	0.25	474.41	434.6	1.72
30GPCSF1	0.5	0.5	494.43	478.7	6.01
30GPCSF1.5	1	0.5	520.89	518.4	11.7
30GPCSF2	1.5	0.5	494.96	558.1	7.2

Table 5 : Experimental results of M70 grade GPC short columns

Column Specification	% of fibers		Ultimate load (P_u) kN	Theoretical Load (kN)	Reserve Strength (Exp) (%)
	SF	PP			
70GPCCF0	0	0	778.9	753.4	0
70GPCCF0.5	0.25	0.25	842.1	818.5	8.10
70GPCCF1	0.5	0.5	865.7	883.6	11.13
70GPCCF1.5	1	0.5	881.2	948.7	13.12
70GPCCF2	1.5	0.5	874.8	1013.8	12.30
70GPCSF0	0	0	768.4	743.1	0
70GPCSF0.5	0.25	0.25	831.0	807.7	8.15
70GPCSF1	0.5	0.5	854.5	872.2	11.20
70GPCSF1.5	1	0.5	869.8	936.8	13.20
70GPCSF2	1.5	0.5	863.5	1001.4	12.4

The specification of the columns are given by using the grade of concrete(M30 &M70) and the type of material and geometry along with fiber volume fraction(GPCCF, GPCSF)

2.3.2 Influence of Fibers on GPC Elements

The GPC short columns of two grades of concrete without fibers failure mode is as follows:

a. a. As compared to HFRGPC short columns, the concrete cover on these columns spalled off and the cracks penetrated the concrete quite earlier.

b. b. The samples for the two grades of concrete had all of their coverings spalled, and cracks quickly appeared upon loading. These cracks widened upon further loading.

c. At the maximum load, the columns broke abruptly under compression due to the longitudinal steel bars failing, and the concrete at the upper half of the column was crushed.

d. d. The concrete cover at the failure location spalled with exposed reinforcement, and the failure pattern was mostly vertical fractures at one corner and diagonal cracks close to the edge. The middle of the column had diagonal cracks, one side had horizontal cracks, and the other side had diagonal cracks. Similar to this, the failure appeared as either vertical cracks at the ends of the specimens or diagonal cracks at the middle or ends of the columns.

The GPC short columns of two grades of concrete with fibers failure mode is as follows:

a. With the application of load, the micro cracks are observed firstly and later the spalling of concrete has taken place as the load reaches to ultimate value, the cracks are wide open and failure has taken place with the yielding of main reinforcement and fracture of the fibers in matrix of the concrete. This is because the fibre matrix in the concrete prevents the concrete from peeled off and becoming debris. In a similar pattern, it was seen that the specimen's crack pattern drastically changed as the percentage of fibresincreases.

From table 4, it can be stated that the ultimate load carrying capacity of the circular columns is more when compared with square columns and with the inclusion of fibers(0-2%), the reserve strength of the column specimens increases in the range of 1.7%-11.7% up to 1.5% and 6-7.2% for 2% V_f respectively for two types of columns for normal strength grade GPC.

From table 5, it can be stated that the ultimate load carrying capacity of the circular columns is more when compared with square columns and with the inclusion of fibers (0-2%), the reserve strength of the column specimens increases in the range of 8.1%-13.12% up to 1.5% and 12.3-12.4% for 2% V_f respectively for two types of columns for high strength grade GPC.

The influence of hybrid fibers on the ultimate load carrying capacity of the two grades of GPC short columns are furnished in Fig.15and 16. A correlation is studied between the ultimate loads in terms of theoretical and experimental loads and volume fraction of fibers, a good agreement is achieved between them for two grades of mixes and is shown in Fig.17.

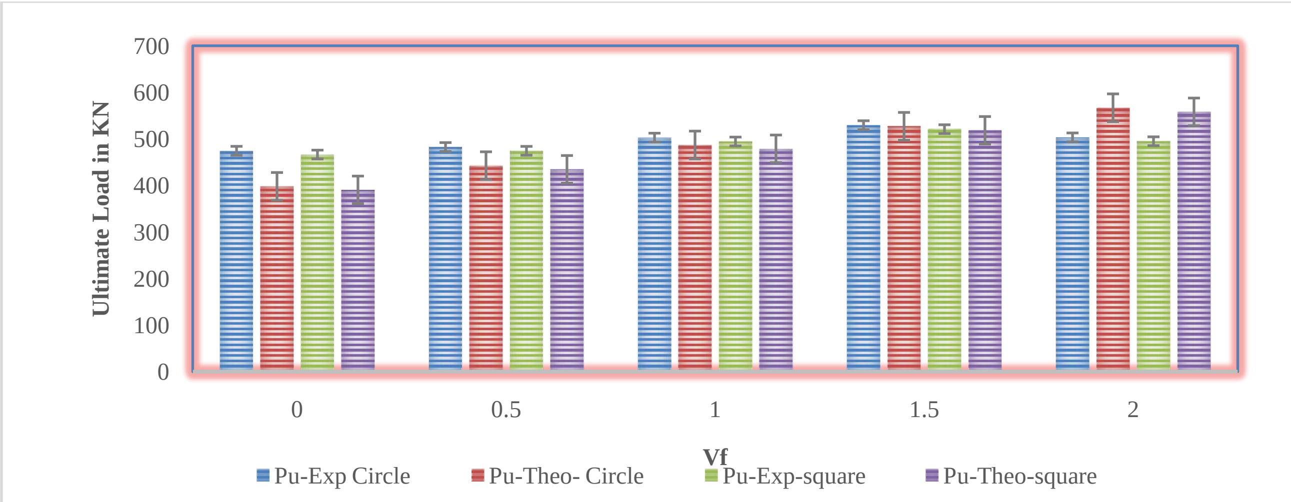

Fig.15 Influence of volume fraction of fibers on Ultimate Load capacity of normal grade GPC short columns.

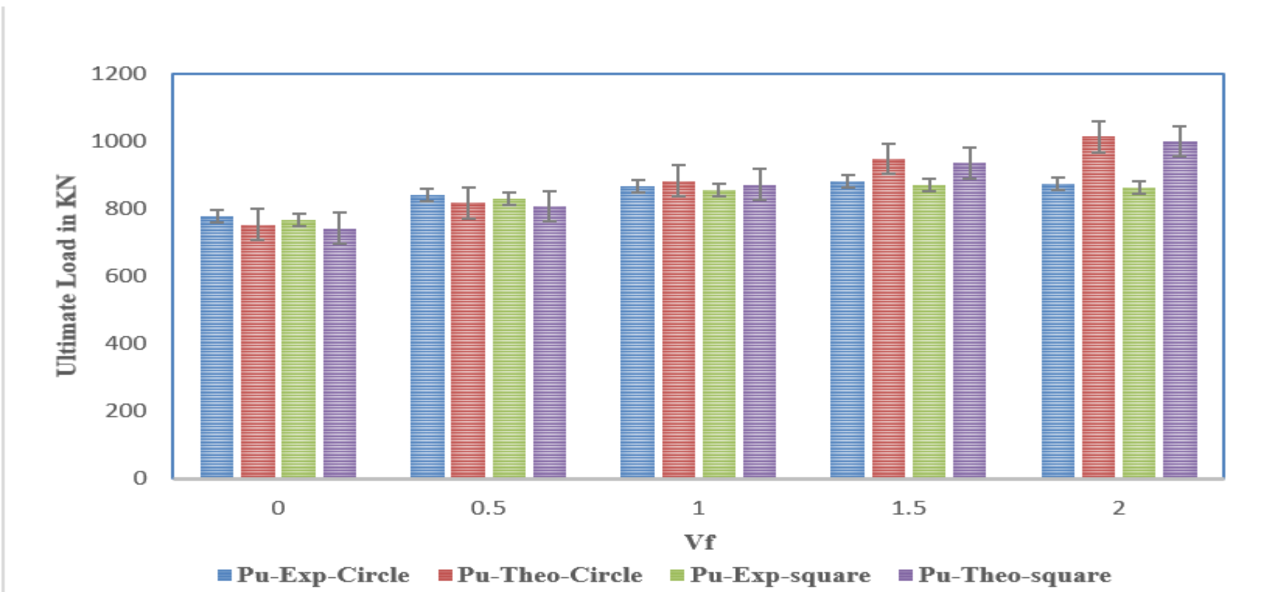

Fig.16 Influence of volume fraction of fibers on Ultimate Load capacity of high strength GPC short columns

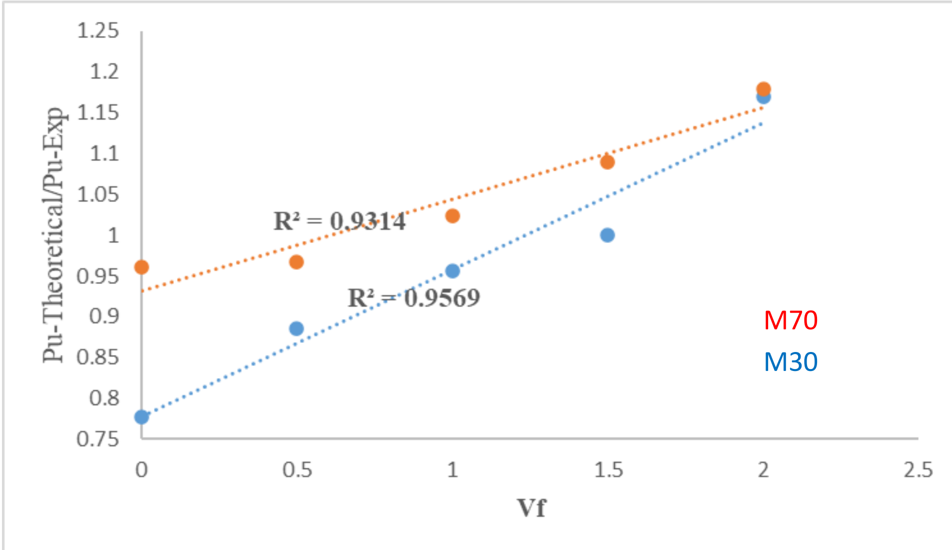

Fig.17 Correlation between V_f and Pu_{theo}/Pu_{exp}

3.0 Conclusions

Under Uni-axial Compressive loading, the two types of short columns with and without hybridization of fibers are investigated. A total of 20 short columns are prepared and tested for uni axial compression loading. The mechanical strength characteristics along with performance aspects in terms of uni-axial compression are studied and presented. The furnished are the conclusions of the current study.

1.The workability of the GPC mixes decreases with the increase in the percentage of the fibre content. The amount of fiber in concrete has an indirect relationship with workability since fiber makes fresh concrete harsh, which changes the slump value.

2. The highest percentage increase in compressive, tensile, and flexural strength is observed with 1.5% hybrid fibres compared to other percentage fibre additions in M30 and M70 grade concrete.

3. The enhancement in compression, tensile, and flexural strengths are 16%, 63.63%, and 50%, respectively, in M30 grade concrete compared to the control mix (M1),and the similar trend is observed in M70 grade concrete and the enhancement in compression, tensile, and flexural strengths are 15.78%, 25.36%, and 55%, respectively, compared to the control mix (M6).

4. An empirical equation is proposed to predict the compressive strength of GPC with and without fibers (up to 2% fiber dosage), by which the ultimate load carrying capacity of the short columns can be predicted for normal and high strength grades of geopolymer concrete.

5.The experimental ultimate load carrying capacity (Pu_{exp}) are in line with the theoretical values(Pu_{theo}) that are estimated by the IS code provisions. Replacing the fck value with the f^1_{ck} value in equation (1), the modified equation can be extended to fiber-reinforced short columns for predicting their ultimate load carrying capacity.

6. The reserve strengths of the normal and high-strength concretes with and without fibers are in the range of 1.7–13%, respectively, for varied volume fractions of fibers, and this is due to the influence of variation in the hybridization of fiber content on the mechanical strength characteristics of the binding matrix.

7. A good correlation is achieved between the volume fraction of fibers and the ratio between the theoretical ultimate load and the experimental ultimate load.

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