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Strength and Durability of Hybrid Fibre Reinforced Binary Blend Geopolymer Concrete

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ABSTRACT

This paper deals with an investigation on the influence of hybrid fibres on the strength and durability of binary blend geopolymer concrete. Geopolymer concrete was prepared using Fly ash and GGBS as source material and mix design was carried out as per the guidelines of Professor Rangan of Curtin University, Australia. Different fly ash-GGBS proportions namely 50-50%, 60-40%, 70-30%, 80-20% and 90-10% were considered. The tests on Geopolymer concrete reveal that the compressive strength increases as the percentage of GGBS increases up to 30%. Hence the combination of 70% fly ash and 30% GGBS was considered as a base material. In order to improve the engineering properties of the Geopolymer concrete, hybrid fibres which consist of metallic and non-metallic fibres were introduced in the base material. Metallic fibres considered was crimped steel fibres with different percentages of volume fraction viz. 0.5% and 1.0% and non-metallic fibres considered was basalt fibres with different percentages of volume fraction viz. 0.1%, 0.2% and 0.3%. Strength parameters such as compressive strength, split tensile strength, modulus of rupture and modulus of elasticity were obtained for various combinations of steel and basalt fibres. Similarly durability parameters which include permeability, water absorption, marine attack and sulphuric acid attack were also evaluated. The combination of fibres having 0.5% steel and 0.3% basalt gave better results with regard to both strength and durability of binary blend Geopolymer concrete.

Keywords: Strength, durability, geopolymer concrete, hybrid fibres

1.0 INTRODUCTION

Introduction of short randomly oriented steel fibres in the concrete mix improves several engineering properties (Naaman, 2003 and Swamy, 1981). Properties of fibre reinforced concrete rely upon many factors such as type, strength, aspect ratio and volume fraction of fibres. Each type of fibre is effective with respect to some specific functions. When these different types of fibre are added to the concrete, a composite known as hybrid fibre reinforced concrete is obtained. Hybrid types of fibres control cracks in various stages (Banthia *et al*. 2014; Antonio *et al*. 2017). While small and soft fibres are effective in arresting cracks at micro level, large and strong fibres will be effective in controlling cracks at macro level.

The hybrid fibre reinforced cementitious composite has better engineering properties than ordinary fibre reinforced composite because of the fact that one type of fibre efficiently utilizes the properties of other fibres (Ganesan *et al*., 2012; Banthia and Soleimani, 2005). The review of literature indicates that many attempts have been made in the past on the hybrid fibre reinforced cement concrete (Ganesan *et al*., 2012). However, only limited attempts have been made on the effect of hybrid fibres on geopolymer concrete. In view of this an experimental investigation was carried out to study the strength and behaviour of hybrid fibre reinforced geopolymer concrete (HFRGPC). This attempt mainly focuses on evaluation of the engineering and durability properties of hybrid fibre reinforced geopolymer concrete.

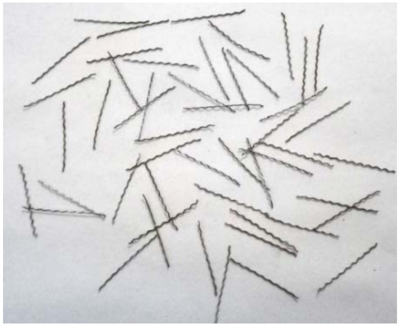
2.0 EXPERIMENTAL PROGRAMME

2.1 Materials used

Low calcium (ASTM Class F) fly ash and GGBS were used as source materials. The fine aggregate consist of river sand passing through 4.75mm IS sieve and conforming to grading zone II of IS: 383-1970 (reaffirmed 2002), with a specific gravity of 2.55 and coarse aggregate of 12 mm size with a specific gravity of 2.70 were used. Figure.1shows crimped steel and basalt fibres and Table.1 gives the properties of fibres. In order to get desired workability a naphthalene based superplasticer was used.

2.2 Design of geopolymer concrete

The geopolymer concrete was designed based on the guidelines provided by Rangan (2008). The main objective of the mix design was to obtain a compressive strength of M40 grade with a satisfactory workability of 75mm to 125mm slump. The activator solution was prepared using sodium silicate and sodium hydroxide. The ratio of sodium silicate solution to sodium hydroxide solution by mass was taken as approximately 2.5. The value of alkaline liquid to fly-ash ratio by mass has to be within the range 0.30 and 0.45. In this investigation the ratio of sodium silicate to sodium hydroxide by mass was obtained, as suggested by Rangan (2010), and a value of 0.36 was selected based on several trial mixes. All the aggregates have to be in saturated surface dry condition. The ratio of water to geopolymer solids by mass was obtained from the Table 2 as suggested by Rangan (2008). Wet mixing time has to be at least 4 minutes. Geopolymer concrete has to be steam cured at 60˚ C for 24 hours after casting.



(i) Steel fibres (Crimped)

(ii) Basalt fibres

Fig. 1. Fibres used

Table 1. Properties of fibres

Type of Fibre	Crimped steel	Basalt
Length of fibre (mm)	30	18
Diameter of fibre (mm)	0.45	0.013
Aspect ratio	66	1384
Tensile strength (N/mm^2)	800	410 to 487

2.2 Variables

In order to obtain a binary blend base material the following procedure was adopted. To start with, a binary blend base material consisting of different proportions of fly ash (FA) and GGBS as shown in Table 3 was obtained and tests were conducted on the mix combination.

Table 2. Data for design of GPC mixtures (Rangan, 2008)

Water to geopolymer solids ratio, by mass	Workability	Design compressive strength, MPa
0.16	Very stiff	60
0.18	Stiff	50
0.20	Moderate	40
0.22	High	35
0.24	High	30

Table 3. Different proportion of Fly ash and GGBS

SL No	Designation of Mix	Fly Ash (FA)	GGBS
1	F50G50	50%	50%
2	F60G40	60%	40%
3	F70G30	70%	30%
4	F80G20	80%	20%
5	F90G10	90%	10%
6	F100G0	100%	0%

Fly ash, GGBS and aggregates in saturated surface dry condition were first mixed for about 5 minutes. Then 14 molar sodium hydroxide solution concentrations was prepared by dissolving sodium hydroxide pellet in water together, at least one day prior to casting. Then alkaline liquid was mixed with super plasticizer and extra water, if any required. The solution, thus prepared was added to dry materials and the mixing continued for about 10 minutes. The detail of the mix proportions of geopolymer concrete is shown in Table 4.

Table 4. Mix proportions of geopolymer concrete

Materials (kg/m^3)	Specimen Designation					
	F100 G0	F90 G10	F80 G20	F70 G30	F60 G40	F50 G50
Coarse aggregates	975	975	975	975	975	975
Fine aggregate	285	285	285	285	285	285
Fly ash	639.0	575.1	511.2	447.3	383.4	319.5
GGBS	0	63.9	127.8	191.7	255.6	319.5
Sodium silicate solution	180	180	180	180	180	180
Sodium hydroxide solution (14 Molar)	72	72	72	72	72	72
Extra water	52	53	56	57	67	68
Super plasticizer	7.50	7.53	7.67	8	8	8

Cubes of size 150mm were cast and after three days of rest period, the specimens were kept in a steam curing chamber at a temperature of 60º C for 24 hours. Then the specimens were kept in the laboratory for 25 days. Compressive strength of these specimen were obtained by testing the cubes. Results of compression test are given in Table 5. It may be seen from the table that the compressive strength given by the combination F70G30 is better than the other combinations. Hence F70G30 was taken as the base material for further studies.

Table 5. Results of compression test

Mix Abbreviation	Cube Compressive Strength (N/mm^2) 7 days	14 days	28 days	56 days	90 days
F50G50	46.28	48.25	49.73	50.22	50.35
F60G40	44.72	46.12	48.05	48.52	49.65
F70G30	46.83	48.78	50.24	50.72	52.3
F80G20	44.05	45.93	47.33	47.79	47.91
F90G10	42.7	44.41	45.87	46.32	46.44
F100G0	39.74	40.07	40.42	41.23	41.37

2.3 Casting of HFRGPC specimen

In order to improve the engineering properties of the geopolymer concrete, hybrid fibres which consist of metallic and non-metallic fibres were introduced in the base material. The quantities of steel fibres and basalt fibres were taken according to the volume fraction and these were then added while mixing.

Table 6 gives the details of HFRGPC specimens. In order to obtain the basic properties such as compressive, flexural, split tensile and modulus of elasticity of HFRGPC, 150 mm cubes, 150 mm X 300 mm cylinders, 150 mm X 150 mm X 700 mm prisms were cast. The freshly mixed GPC was then poured into the mould layer by layer so that the total number of layers was three and each layer was vibrated for 15 seconds for proper compaction. The top surface was levelled to a smooth finish and the moulds were covered with plastic sheet to prevent loss of moisture. The covered specimens were allowed to rest for 3 days. They were then transferred to a steam curing chamber where they were cured for 24 hours at a constant temperature of 60˚C as shown in Fig. 2. Then the specimen were kept in the laboratory temperature for 25 days prior to testing.

Table 6. Details of specimen and variables

Serial No.	Specimen designation	Volume fraction of fibre% Steel	Basalt
1	GPC	0	0.0
2	BFRGPC1		0.1
3	BFRGPC2		0.2
4	BFRGPC3		0.3
5	SFRGPC1	0.5	0.0
6	HFRGPC1		0.1
7	HFRGPC2		0.2
8	HFRGPC3		0.3
9	SFRGPC2	1	0.0
10	HFRGPC4		0.1
11	HFRGPC5		0.2
12	HFRGPC6		0.3

Fig. 2. Specimen in steam chamber curing

3.0 DISCUSSIONS OF RESULTS

Engineering properties such as cube compressive strength, flexural strength, split tensile strength and modulus of elasticity are shown in Table 7. It can be seen that incorporation of fibres into GPC improves all the engineering properties. The improvement in compressive, flexural and split tensile strength is about 11%, 33% and 37% respectively. The improvement in the modulus of elasticity was not significant and it is about 18%. The reason for the improvement may be attributed to the following: while the micro fibres such as basalt fibres control the micro cracks, the steel fibres bridge across the macro cracks and hence the cracks could not propagate in the same plane and takes a deviated path resulting in mixed mode propagation and this results in the demand for higher energy for further propagation of cracks leading to improved strength.

3.1 Relation between strength parameters

An attempt is made to get a relation between the split tensile strength and compressive strength of fibre reinforced GPC. To start with several factors which were though of affecting the compressive strength were identified and related against split tensile strength. A parameter called as fibre factor, $F\sqrt{f_{ck}}$ which represents the physical properties is fibres and strength of GPC was found to correlate better with split tensile strength f_{ct}.

Here $F = F_s + F_b$ and (1)

$$F_s = \frac{l_s}{d_s} v_{fs} \eta_{bs} \quad \text{(for steel fibres)} \qquad (2)$$

and

$$F_b = \frac{l_b}{d_b} v_{fb} \eta_{bb} \quad \text{(for basalt fibres)} \qquad (3)$$

η_{bs} and η_{bb} are bond efficiency factors for crimped steel fibres and basalt fibres respectively. The bond efficiency factor depends on the shape of the fibre and can be assumed as 1.2 for crimped steel fibres and 1.0 for round straight fibres (Swamy and Al-Ta'an, 1981).

Table 7. Hardened concrete properties

Mix Designation	f_c [N/mm^2]	f_{ct} [N/mm^2]	f_{cr} [N/mm^2]	E_c x 10^4 [N/mm^2]
GPC	46.09	4.02	6.45	2.25
BFRGPC1	48.85	4.16	7.23	2.35
BFRGPC2	49.35	5.28	9.01	2.65
BFRGPC3	49.78	4.99	8.32	2.45
SFRGPC1	49.93	5.38	8.5	2.65
HFRGPC1	50.45	5.42	9.01	2.7
HFRGPC2	51.85	5.5	9.32	2.75
HFRGPC3	53.15	5.55	9.28	2.75
SFRGPC2	50.96	5.5	9.23	2.55
HFRGPC4	51.00	5.4	9.25	2.60
HFRGPC5	50.85	5.4	9.10	2.7
HFRGPC6	50.3	5.3	9.15	2.5

Figure 3 shows the relation between f_{ct} and $F\sqrt{f_c}$ and the regression equation for the best fit line thus obtained is:

$$f_{ct}= 0.1794\ F\sqrt{f_c}+ 4.11 \qquad (4)$$

where f_{ct} and f_c are in N/mm^2.

Similarly a regression equation for the flexural strength f_{cr} and $F\sqrt{f_c}$ was obtained. Figure 4 shows the best fit line and the regression equation is given below.

$$f_{cr} = 0.275\ F\sqrt{f_c} +7.06 \qquad (5)$$

where f_{cr} and f_c are in N/mm^2.

On similar lines, the modulus of elasticity E_c was plotted against the parameter $F\sqrt{f_c}$ and shown in Fig. 5. The regression equation for plot is:

$$E_c \times 10^{-3} = 0.1502x + 2.22 \qquad (6)$$

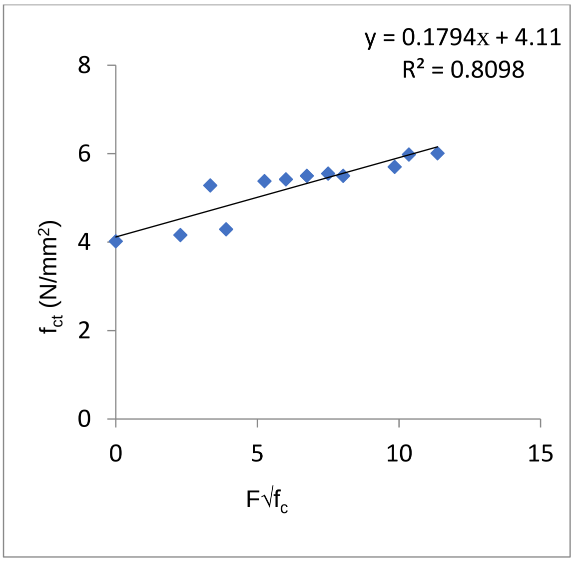


Fig. 3. Relation between f_{ct} and $F\sqrt{f_c}$

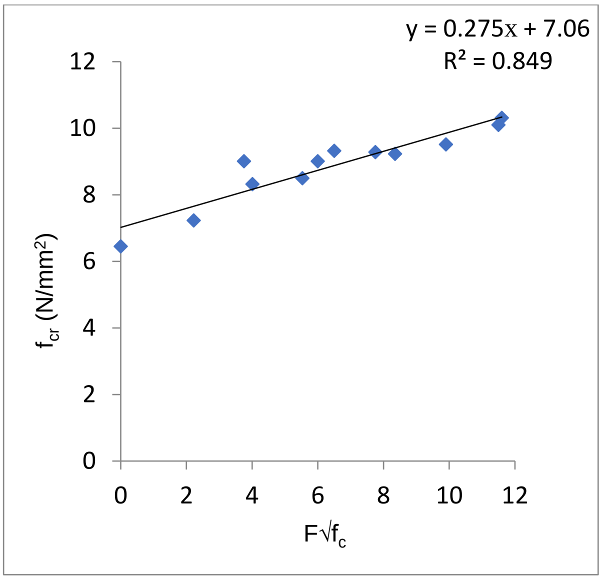


Fig. 4. Relation between f_{cr} and $F\sqrt{f_c}$

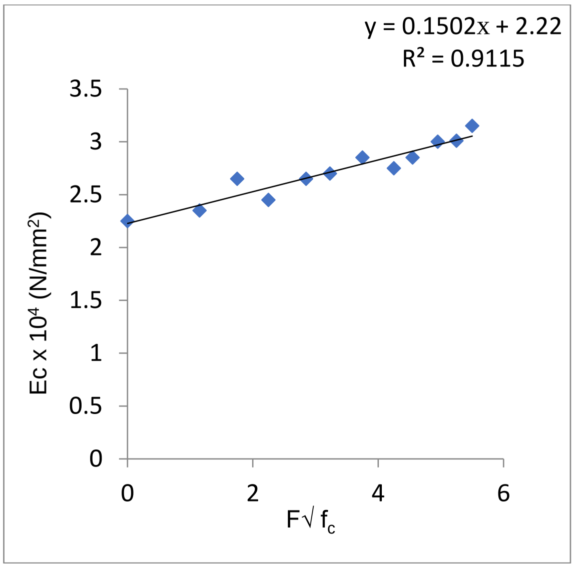


Fig. 5. Relation between E_c and $F\sqrt{f_c}$

4. DURABILITY

Durability parameters considered in this study included the following:

(i) Water Permeability test as per BIS 3085-1965 (reaffirmed 2002) on cylindrical specimens of diameter 150mm and height 150mm.

(ii) Water absorption test according to BIS 1237-1980 (reaffirmed 2001) using cubes of size 100×100×100 mm.

(iii) Marine attack test as per ASTM D1141 on cube of size 100mm.

(iv) Sulphuric Acid attack test on 100mm cubes.

4.1 Result and Discussion

Table 8 gives the durability test results. From Table 8, it can be noted that the water absorption of the specimens ranges from 0.72 to 1.73% and which is well below the values of 10% for a good concrete (Neville,2005). The coefficient of permeability ranges from 2.339X 10^{-11} to 4.655 X 10^{-11} cm/s. When fibres are added, there is a substantial reduction in coefficient of permeability. In case of normal strength concrete the value of coefficient of permeability ranges from 1 X 10^{-10} to 3 X 10^{-10} cm/s (Mehta and Monteiro, 1997) and the results of this study indicate that coefficient of permeability of GPC and HFRGPC are less than the value for conventional concrete. Addition of fibres in the hybrid form reduces the values further, up to volume fraction of steel 0.5% and basalt fibre 0.3%. Beyond this combination there is an increase in the values of coefficient of permeability. This may be due to balling effect of fibres at higher percentage of volume fractions.

Table 8. Durability test results

Mix Designation	Water absorption (%)	K × 10^{-11} (cm/s)	Change in mass (%)	
			Marine attack	Sulphuric acid attack
GPC	1.63	4.655	2.25	1.53
BFRGPC1	1.73	2.635	1.83	1.47
BFRGPC2	1.69	2.896	1.63	1.41
BFRGPC3	1.51	2.996	1.32	1.32
SFRGPC1	1.38	2.523	1.19	1.22
HFRGPC1	1.16	2.339	0.95	1.19
HFRGPC2	0.95	2.496	0.9	1.10
HFRGPC3	0.72	2.593	0.3	1.00
SFRGPC2	0.88	2.763	0.87	0.91
HFRGPC4	0.96	3.106	0.79	0.83
HFRGPC5	1.11	3.336	0.617	0.71
HFRGPC6	1.29	3.593	0.40	0.70

The permeability and the water absorption are generally affected by the pore structure of the geopolymer mortar and the characteristics of interface between the mortar and the aggregate. Surface water absorption has significant influence on the permeability. When geopolymer concrete is reinforced with fibres because of the interception of fibres which bridge across the micro cracks the surface water absorption and permeability reduces. At higher content of fibres, due to balling effect the water absorption increases. The coefficient of permeability is also affected on a similar fashion.

In this investigation hybrid fibres with a combination of 0.5% volume of fraction of steel fibre and 0.3% volume of fraction of basalt fibre (HFRGPC3) yielded a lower value of water absorption. On the other hand the specimen with 0.5% steel fibre and 0.1%basalt fibre (HFRGPC1) yielded a lower value of permeability of 2.339 X 10^{-11} cm/s, which is close to a value of 2.523 X 10^{-11} cm/s given by HFRGPC3 specimen which has given the lower value of water absorption. The minor difference may be due to the variation of internal water absorption which had insignificant effect on permeability (Zhang and Zong, 2014).

The marine and sulphuric acid attack tests indicate that the addition of fibres in the hybrid form reduces the change in mass substantially. Considering the strength and durability tests it may be seen that combination of fibres having 0.5% steel and 0.3% basalt appear to perform better than other combination of fibres.

5.0 CONCLUSIONS

1) Incorporation of steel and basalt fibres in binary blend GPC increases all the engineering properties such as the compressive, tensile, flexural strengths of GPC and modulus of elasticity of GPC.

2) The incorporation of hybrid fibres improves also several durability parameters of the binary blend GPC.

3) The GPC specimen with the combination of 0.5% steel fibres and 0.3% basalt fibres exhibited better performance in terms of strength and durability.

Notations

E_c– modulus of elasticity of concrete
F– fibre factor
F_b–fibre factor for basalt fibre
F_s–fibre factor for steel fibre
K–coefficient of permeability
d_b– diameter of basalt fibre
d_s– diameter of steel fibre
f_c– compressive strength
f_{cr}– flexural strength
f_{ct}– split tensile strength
l_b– length of basalt fibre
l_s– length of steel fibre
v_{fb}– volume fraction of basalt fibres
v_{fs}–volume fraction of steel fibres
η_{bb}–bond efficiency factors for basalt fibres
η_{bs}–bond efficiency factors for crimped steel fibres

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