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PROPERTIES OF GLASS FIBRE REINFORCED GEOPOLYMER CONCRETE COMPOSITES

K. Vijai[*a], R. Kumutha[a] and B.G.Vishnuram[b]
[a]Department of Civil Engineering, Sona College of Technology, Salem, Tamilnadu, India
[b]Easa College of Engineering & Technology, Coimbatore, Tamilnadu, India

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ABSTRACT

In order to address environmental effects associated with Portland cement, there is need to develop alternative binders to make concrete. An effort in this regard is the development of geopolymer concrete, synthesized from the materials of geological origin or by product materials such as fly ash, which are rich in silicon and aluminum. This paper presents results of an experimental program on the mechanical properties such as density, compressive strength, split tensile strength and flexural strength of Geopolymer Concrete Composites (GPCC) containing 90% Fly ash (FA), 10% Ordinary Portland Cement (OPC), alkaline liquids and glass fibers. The effect of inclusion of glass fibers on the density, Compressive Strength, Split Tensile strength and Flexural strength of hardened GPCC was studied. Alkaline liquid to fly ash ratio was fixed as 0.4 with 10% of fly ash replaced by OPC in mass basis. Glass fibers were added to the mix in volume fractions of 0.01%, 0.02% and 0.03% by volume of concrete. The influence of fiber content in terms of volume fraction on the compressive strength, split tensile strength and flexural strengths of GPCC is presented. Based on the test results, empirical expressions were developed to predict split tensile strength and flexural strength of glass fiber reinforced GPCC in terms of its compressive strength.

Keywords: Fly ash; geopolymer concrete composites; alkaline liquids; glass fibers; density; compressive strength; split tensile strength; flexural strength

1. INTRODUCTION

Geopolymer is a type of amorphous alumino-silicate product that exhibits the ideal properties of rock-forming elements, i.e., hardness, chemical stability and longevity. The properties of geopolymer include high early strength, low shrinkage, freeze-thaw resistance, sulphate resistance and corrosion resistance. These high-alkali binders do not generate any alkali-aggregate reaction [1]. The geopolymer binder is a low-CO_2 cementious material. It does not rely on the calcination of limestone that generates CO_2. This technology can save

[*] E-mail address of the corresponding author: vijai_me @yahoo.co.in (K. Vijai)

up to 80% of CO_2 emissions caused by the cement and aggregate industries [2]. It is reported that the worldwide cement industry contributes around 1.65 billion tons of the greenhouse gas emissions annually [3-5]. Due to the production of Portland cement, it is estimated that by the year 2020, the CO_2 emissions will rise by about 50% from the current levels [6-7]. Therefore, to preserve the global environment from the impact of cement production, it is now believed that new binders are indispensable to replace Portland cement. In this regard, the geopolymer concrete is one of the revolutionary developments related to novel materials resulting in low-cost and environmentally friendly material as an alternative to the Portland cement [8,9]. Geopolymer Concrete is an innovative binder material and is produced by totally replacing the Portland cement. It is demonstrated that the geopolymeric cement generates 5–6 times less CO_2 than Portland cement [10]. Therefore, the use of geopolymer technology not only significantly reduces the CO_2 emissions by the cement industries, but also utilises the industrial wastes and/or by-products of alumino-silicate composition to produce added-value construction materials [3,11].

Also the concept of using fibers as reinforcement is not new .By the 1960s, steel, glass (GFRC), and synthetic fibers such as polypropylene fibers were used in concrete, and research into new FRCs continues today. Some types of fibers produce greater impact, abrasion, and shatter resistance in concrete. Concerning the structural applications, fiber concrete possesses many advantages compared to the traditional structural concrete. Yeol Choi et al. investigated the relationship between the splitting tensile strength and compressive strength of glass fiber reinforced concrete (GFRC) and polypropylene fiber reinforced concrete (PFRC). The splitting tensile strength and compressive strength of GFRC and PFRC at 7, 28 and 90 days were used an test results indicated that the addition of glass and polypropylene fibers to concrete increased the splitting tensile strength of concrete by approximately 20–50%, and the splitting tensile strength of GFRC and PFRC ranged from 9% to 13% of its compressive strength. Based on this investigation, a simple 0.5 power relationship between the splitting tensile strength and the compressive strength was derived for estimating the tensile strength of GFRC and PFRC [12].

Mazaheripour et al. analyzes the impact of polypropylene fibers on the performance of light weight self compacting concrete at its fresh condition as well as its mechanical properties at the hardened condition and they found that applying 0.3% volume fractions of polypropylene fiber to the light weight self compacting concrete resulted in 40% reduction in the slump flow (from 720 mm to 430 mm Polypropylene fibers did not influence the compressive strength and elastic modulus of light weight self compacting concrete, however applying these fibers at their maximum percentage volume determined through this study, increased the tensile strength by 14.4% in the splitting tensile strength test, and 10.7% in the flexural strength [13].

Songa et al. investigated the strength potential of nylon-fiber-reinforced concrete versus that of the polypropylene-fiber-reinforced concrete, at a fiber content of 0.6 kg/m3. The compressive and splitting tensile strengths and modulus of rupture of the nylon fiber concrete improved by 6.3%, 6.7%, and 4.3%, respectively, over those of the polypropylene fiber concrete. On the impact resistance, the first-crack and failure strengths and the percentage increase in the post first-crack blows improved more for the nylon fiber concrete than for its polypropylene counterpart. In addition, the shrinkage crack reduction potential also improved more for the nylon-fiber-reinforced mortar. The above-listed improvements stemmed from the nylon fibers registering a higher tensile strength and possibly due to its better distribution in concrete [14].

Jagannadha Rao et al. determined the suitability of glass fibers for use in structural recycled aggregate concrete (RCA) of high strength. The fresh and hardened state properties of partially replaced recycled aggregate concrete, with varying percentages of glass fibers, are compared with the corresponding conventional aggregate concrete. The compressive, split tensile and flexural strengths of M50 grade concrete with 0% RCA and 50% RCA have increased as the fiber content increased. The maximum values of all these strengths were obtained at 0.03% of fiber content for both the concretes of 0% RCA and 50% RCA. Large deflections of beams before failure indicated improved ductility with the addition of fibers [15].

The mechanical properties of GFRAC with M20 & M40 grade concretes, for different replacements of Recycled Concrete Aggregate (RCA) in Natural Aggregate (NA) are presented by Prasad et al. [16]. It was observed that there was 10-17 % increase in split tensile strength and about 10-14 % improvement in flexural strength with fiber addition in recycled aggregate concrete. There is an improvement in the modulus of elasticity of concrete. The values of split, flexure and modulus of elasticity obtained were also compared with the Indian standard codal Provisions. The increased energy absorption capacity in GFRRAC indicates higher toughness and better post elastic deformations in the event of seismic actions.

Literatures indicated that several researchers have investigated the effect of inclusion of fibers in concrete consisting of either 100% cement or partial replacement of cement by fly ash. The present investigation is designed to evaluate the mechanical properties of glass fibre reinforced Geopolymer Concrete Composites consisting of 90% Fly ash, 10% Cement and alkaline liquids.

2. EXPERIMENTAL INVESTIGATION

2.1 Materials

Low calcium fly ash (ASTM class F) collected from Mettur thermal power station was used as the source material to make geopolymer concrete in the laboratory. Ordinary Portland cement with a specific gravity of 3.15 was used in casting the specimens. Fine Aggregate (sand) used is clean dry river sand. The sand is sieved using 4.75 mm sieve to remove all the pebbles. Fine aggregate having a specific gravity of 2.81, bulk density of 1693 kg/m^3 and fineness modulus of 2.75 was used. Coarse aggregates of 19 mm maximum size having a fineness modulus of 6.64, bulk density of 1527 kg/m^3 and specific gravity of 2.73 were used. Water conforming to the requirements of water for concreting and curing was used throughout.

In this investigation, a combination of Sodium hydroxide solution and sodium silicate solution was used as alkaline activators for geopolymerisation. Sodium hydroxide is available commercially in flakes or pellets form. For the present study, sodium hydroxide flakes with 98% purity were used for the preparation of alkaline solution. Sodium silicate is available commercially in solution form and hence it can be used as such. The chemical composition of sodium silicate is: Na_2O-14.7%, SiO_2-29.4% and water −55.9% by mass. In this work alkali resistant glass fibers of 6mm length and 0.014mm nominal diameter having a density of 2680 kg/m^3 were used.

2.2 Mix Design of geopolymer concrete composite

In the design of geopolymer concrete (GPC mix), coarse and fine aggregates together were taken as 77% of entire mixture by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75% to 80% of the entire mixture by mass. Fine aggregate was taken as 30% of the total aggregates. From the past literatures it is clear that the average density of fly ash-based geopolymer concrete is similar to that of OPC concrete (2400kg/m^3).Knowing the density of concrete, the combined mass of alkaline liquid and fly ash can be arrived. By assuming the ratios of alkaline liquid to fly ash as 0.4, 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. Extra water (other than the water used for the preparation of alkaline solutions) and super plasticizer Conplast SP 430 based on Sulphonated Napthalene Polymers were added to the mix by 10% and 3% by weight of fly ash respectively, to achieve workable concrete. This GPC mix has two limitations such as delay in setting time and necessity of heat curing to gain strength. In order to overcome these two limitations of GPC mix, 10% of fly ash was replaced by OPC and the mix design was altered accordingly which results in Geopolymer Concrete Composite (GPCC mix). The mix proportions of GPC and GPCC are given in Table 1.

Table 1: Mix proportions

Mix ID	**Fly ash kg/m^3**	**OPC kg/m^3**	**Fine aggregate kg/m^3**	**Coarse aggregate kg/m^3**	**NaOH solution kg/m^3**	**Na_2SiO_3 solution kg/m^3**	**Extra water kg/m^3**	**Super plasticizer kg/m^3**	**Glass fibers g/m^3**
GPC	394.3	--	554.4	1293.4	45.1	112.6	39.43	11.83	-
GPCC	354.87	39.43	554.4	1293.4	40.56	101.39	55.18	11.83	-
GPCC 1	354.87	39.43	554.4	1293.4	40.56	101.39	55.18	11.83	268
GPCC 2	354.87	39.43	554.4	1293.4	40.56	101.39	55.18	11.83	536
GPCC 3	354.87	39.43	554.4	1293.4	40.56	101.39	55.18	11.83	804

2.3 Preparation of GPCC

To prepare 12 molarity concentration of sodium hydroxide solution, 480 grams (molarity x molecular weight) of sodium hydroxide flakes was dissolved in distilled water and makeup to one liter. The mass of NaOH solids was measured as 354.45 grams per kg of NaOH solution of 12M concentration. The sodium hydroxide solution thus prepared is mixed with sodium silicate solution one day before mixing the concrete to get the desired alkaline solution. The solids constituents of the GPCC mix i.e. fly ash, OPC and the aggregates were dry mixed in the pan mixer for about three minutes. After dry mixing, alkaline solution was added to the dry mix and wet mixing was done for 4 minutes. Finally extra water along with super plasticizer was added to achieve workable GPCC mix. In case of glass fiber reinforced GPCC mixes fibers were added to the wet mix in three different proportions such as 0.01%, 0.02% and 0.03% volume of the concrete.

In this experimental work a total of 102 numbers of concrete specimens were cast with and without glass fibers. The specimens considered in this study consisted of 42 numbers of

150mm side cubes, 30 numbers of 150mm diameter and 300mm long cylinders and 30 numbers of 100 mm×100mm×500mm size prisms.

Before casting machine oil was smeared on the inner surfaces of the cast iron mould. Concrete was poured into the moulds and compacted thoroughly using a table vibrator. The top surface was finished using a trowel. The GPC specimens were removed from the mould after 4 days while the GPCC specimens were removed from the mould immediately after 24 hours since they set in a similar fashion as that of conventional concrete. All the specimens were left at room temperature till the day of testing. Tests for compressive and split tensile strengths were conducted using a 2000kN Digital Compression testing machine and the test for flexural strength was conducted using a 100kN Flexural testing machine. These tests were conducted as per the relevant Indian standard specifications [17,18].

3. RESULTS AND DISCUSSION

3.1 Density

Density of geopolymer concrete composites is presented in Figure 1. Average Density values of Geopolymer concrete composites ranges from 2353 to 2417 kg/m^3. The density of geopolymer concrete composites was found approximately equivalent to that of conventional concrete.

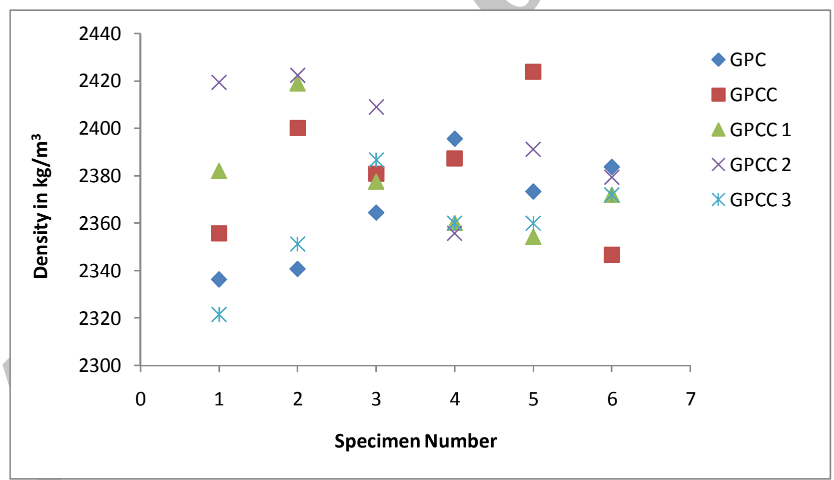

Figure 1. Density of the specimens

3.2 Compressive Strength

The average compressive strength of GPC and GPCC without glass fiber at the age of 7 days and 28 days for both ambient curing and heat curing is given in Table 2. Replacement of 10% of fly ash by OPC in GPC mix resulted in an enhanced compressive strength. The percentage increase in compressive strength due to heat curing is very less in GPCC than GPC in both 7 days and 28 days age of concrete. This may be due to the reason that at ambient curing the heat evolved by hydration of 10% of OPC stimulates the polymerization of 90% of fly ash present in the GPCC mixes. Hence ambient curing is sufficient in case of

GPCC mixes.

The compressive strength of GPCC with and without Glass fibers at the age of 7 days 28 days for ambient curing is represented in Figure 3. As the age of concrete increases from 7 days to 28 days, compressive strength also increases for all the mixes. From the test results it can be seen that, average compressive strengths of GPCC with 0.01% and 0.02% volume fraction of glass fibers were decreased with respect to that of the GPCC mix without fibers, while the compressive strength of GPCC with 0.03% volume fraction of glass fibers were increased with respect to that of the GPCC mix without fibers. The decrease in 28 days compressive strength was about 6% and 16% for addition of 0.01% and 0.02% volume fraction of glass fibers respectively with reference to GPCC mix and increase in 28 days compressive strength was about 6% for addition of 0.03% volume fraction of glass fibers with reference to GPCC mix.

Table 2: Average Compressive Strength of GPC and GPCC Specimens

Age of concrete and type of curing	Average compressive strength in N/mm^2	
	GPC	GPCC
7 days – Ambient curing	7.9	19.83
7 days – Heat curing	21.42	35.16
28 days – Ambient curing	22.18	38.28
28days – Heat curing	28.49	39.47

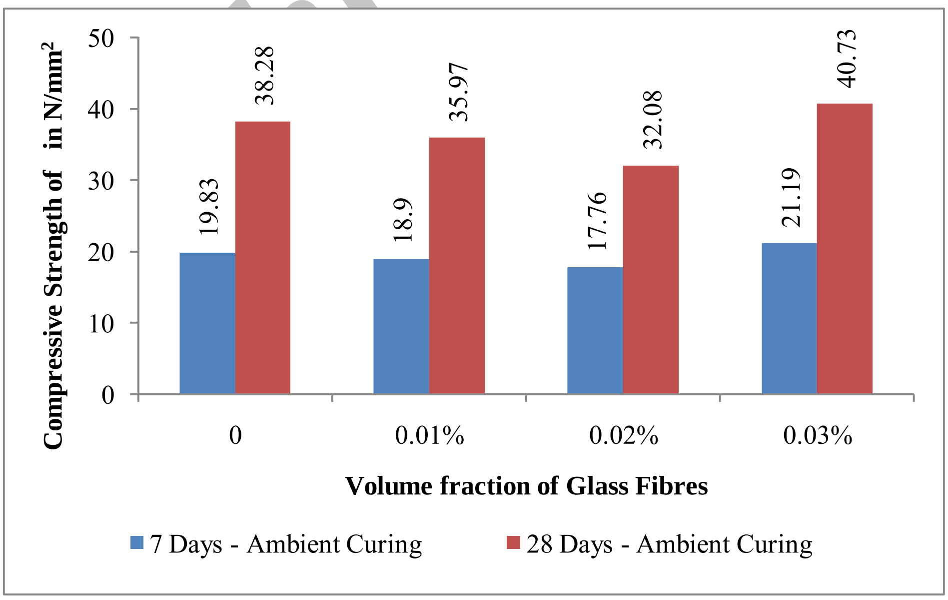

Figure 2. Compressive strength of glass fiber reinforced GPCC

3.3 Split tensile strength

The average tensile strength of GPC and GPCC without glass fiber at the age of 7 days and 28 days for both ambient curing and heat curing is given in Table 3. Replacement of 10% of fly ash by OPC in GPC mix resulted in an enhanced tensile strength. The percentage increase in tensile strength due to heat curing is very less in GPCC than GPC in both 7 days and 28 days age of concrete. Hence ambient curing is sufficient in case of GPCC mixes.

The split tensile strength of GPCC with and without Glass fibers at 7 days and 28 days are represented in Figure 3. From the test results it can be seen that, average tensile strengths of GPCC with 0.01% and 0.02% volume fraction of glass fibers decreases with respect to that of the GPCC mix without fibers, while the tensile strength of GPCC with 0.03% volume fraction of glass fibers increases with respect to that of the GPCC mix without fibers. The decrease in tensile strength was about 27% and 30% for addition of 0.01% and 0.02% volume fraction of glass fibers respectively with reference to GPCC mix and increase in tensile strength was about 1% for addition of 0.03% volume fraction of glass fibers with reference to GPCC mix. Based on the test results of this investigation, using least square regression analysis the equation for predicting the split tensile strength of glass fiber reinforced geopolymer concrete composites in terms of its compressive strength is obtained and given in Eq. 1.

$$f_{st} = 0.339\sqrt{f_{ck}} \tag{1}$$

where,
f_{st} = Split tensile strength of glass fibre reinforced geopolymer concrete composites
f_{ck} = Compressive strength of glass fibre reinforced geopolymer concrete composites

Table 3: Average split tensile strength of GPC and GPCC specimens

Age of concrete and type of curing	Average tensile strength in N/mm^2	
	GPC	**GPCC**
7 days – Ambient curing	0.27	1.22
7 days – Heat curing	1.09	3.00
28 days – Ambient curing	1.17	2.67
28 days – Heat curing	1.33	3.02

3.4 Flexural strength

The average flexural strength of GPC and GPCC without glass fibers at the age of 7 days and 28 days for both ambient curing and heat curing is given in Table 4. Replacement of 10% of fly ash by OPC in GPC mix resulted in an enhanced flexural strength. The percentage increase in flexural strength due to heat curing is very less in GPCC than GPC in both 7 days and 28 days age of concrete. Hence ambient curing is sufficient in case of GPCC mixes.

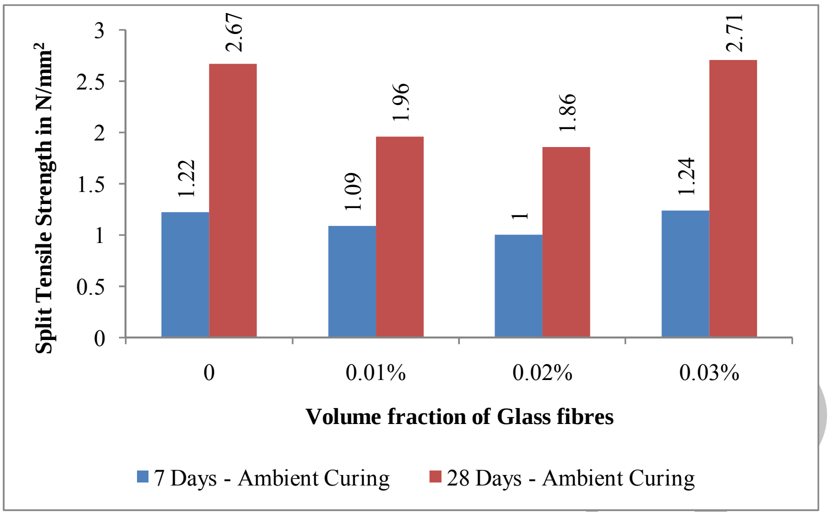

Figure 3. Split tensile strength of glass fiber reinforced GPCC

The flexural strength of GPCC with and without Glass fibers at 7 days and 28 days are represented in Figure 4. From the test results it can be seen that, flexural strengths of GPCC with 0.01% and 0.02% volume fraction of glass fibers decreases with respect to that of the GPCC mix without fibers, while the flexural strength of GPCC with 0.03% volume fraction of glass fibers increases with respect to that of the GPCC mix without fibers. The decrease in flexural strength was about 1% and 12% for addition of 0.01% and 0.02% volume fraction of glass fibers respectively with reference to GPCC mix and increase in flexural strength was about 16% for addition of 0.03% volume fraction of glass fibers with reference to GPCC mix. Based on the test results of this investigation, using least square regression analysis the equation for predicting the flexural strength of glass fiber reinforced Geopolymer Concrete Composites in terms of its compressive strength is obtained and given in Equation 2.

$$f_{st} = 0.947\sqrt{f_{ck}} \quad (2)$$

where,

f_{st} = Split tensile strength of glass fibre reinforced Geopolymer Concrete Composites

f_{ck} = Compressive Strength of glass fibre reinforced Geopolymer Concrete Composites

Table 4: Average flexural strength of GPC and GPCC specimens

Age of concrete and type of curing	Average flexural strength in N/mm^2	
	GPC	GPCC
7 days – Ambient curing	3.0	3.94
7 days – Heat curing	4.4	5.20
28 days – Ambient curing	5.0	5.84
28 days – Heat curing	5.4	6.00

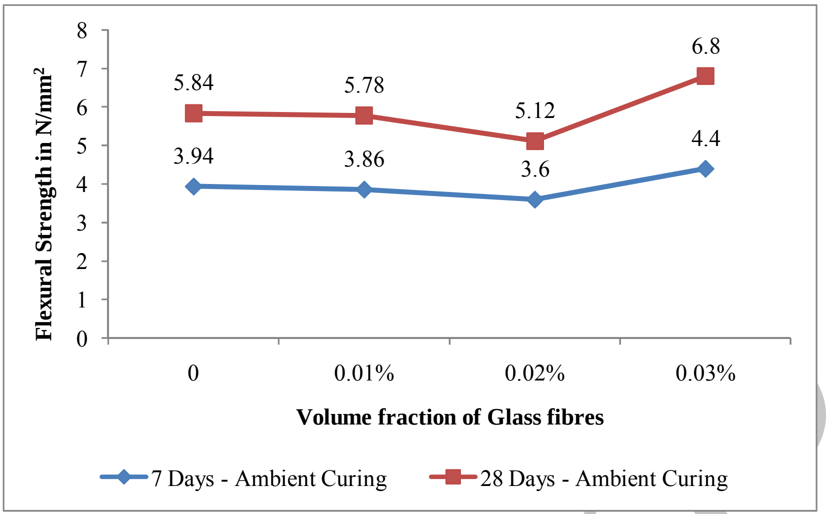

Figure 4. Flexural strength of glass fiber reinforced GPCC

4. CONCLUSIONS

Replacement of 10% of fly ash by OPC in GPC mix eliminates the two limitations of Geopolymer Concrete (GPC mix) such as delay in setting time and necessity of heat curing to gain strength which results in Geopolymer Concrete Composite (GPCC mix). Also replacement of 10% of fly ash by OPC in GPC mix resulted in an enhanced compressive strength, split tensile strength and flexural strength by 73%, 128% and 17% respectively with reference to GPC mix. Addition of 0.03% volume fraction of glass fibers in Geopolymer concrete composites enhanced its mechanical properties. Compressive strength, split tensile strength and flexural strength of glass fiber reinforced Geopolymer concrete composites decreases for addition 0.01% & 0.02% volume fraction of glass fibers. Addition of 0.01% volume fraction of glass fibers resulted in a reduced compressive strength, split tensile strength and flexural strength by 6%, 27% and 1% respectively with reference to GPCC mix. Similarly for addition of 0.02% volume fraction of glass fibers the compressive strength, split tensile strength and flexural strength is decreased by 16%, 30% and 12% respectively with reference to GPCC mix. But for addition of 0.03% volume fraction of glass fibers compressive strength, split tensile strength and flexural strength are enhanced by 6%, 1% and 16% respectively with reference to GPCC mix. Equations for predicting the split tensile strength and flexural strength of glass fiber reinforced Geopolymer Concrete Composites in terms of its compressive strength are obtained by using least square regression analysis from the test results of these investigations.

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