Studies on Basalt Fibre Reinforced Binary Blended Geopolymer Concrete

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ABSTRACT

Rapid population growth demands more infrastructure development, which improves life standard but harms the environment by overexploiting non-renewable natural resources. Concrete is one of the most used construction materials which uses Ordinary Portland Cement (OPC) as binder. Production of OPC is responsible for the emission of large quantities of greenhouse gases. Fly ash-based heat cured geopolymers were introduced as an alternative to OPC binders, which limits its application to precast industry. Ambient cured geopolymers can be produced by utilizing blended source materials. Hence in this study, binary blended geopolymer concrete is developed using fly ash and Ground Granulated Blast furnace slag (GGBFS) as source materials. For improving the tensile properties of the mix, natural fibres like basalt fibres were introduced at 0.25, 0.5, 0.75 and 1% by volume of concrete. The optimum proportion of fibres were finalized based on fresh and hardened properties of the mix. Durability studies like water absorption, sorptivity, thermal conductivity and chemical attack were also conducted. Results of the study indicated that basalt fibre reinforced ambient cured GPC is having comparable mechanical properties and enhanced durability characteristics to that of conventional concrete.

Keywords: Geopolymer concrete, Basalt Fibre, mechanical properties, durability properties

1. Introduction

With the increase in population, the infrastructure development is becoming more crucial. It has big impact on the cement utilization. Since cement manufacturing led to significant consumption of non-renewable natural resources and emits large quantities of green house gases, which adversely affect the environment [1], [2]. From recent data, the cement production resulted in increase of 5-9% of global CO_2 emission [2], [3]. Hence more focus is made on the development of cement-free green building materials as an effort to reduce negative effects of CO_2 emission from the cement industry [3]. Geopolymer binders are one such alternate green binder in concrete. Geopolymers are inorganic polymer formed by polycondensation reaction between alkali activator and alumino-silicate material such as slag, fly ash, volcanic ash, sugar cane bagasse ash, hydrous clay etc. [2], [4], [5]. The performance of geopolymers depends on several parameters like molarity of NaOH solution, types and proportions of source materials, curing regime and temperature, type and grading of aggregate used etc. The reactivity of aluminosilicates during the geopolymerisation process is significantly influenced by the source of precursors. The most commonly used material for producing geopolymers are supplementary cementitious materials (SCMs), such as fly ash and slag, because of their well-known and ideal compositions and properties for the process [3]. Studies showed that geopolymers have better durability characteristics and possess thermal insulation property [6], [7], [8], [9].

Geopolymer concrete is brittle in nature as that of conventional concrete and to improve its tensile properties, fibres were being used. Several researches are conducted on steel fibre and polypropylene fibre

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reinforced GPC. The usage of steel fibres enhances the properties of concrete but it has tendency to get corroded and hence affect the durability [10], [11]. The usage of basalt fibre addresses the above-mentioned problem. Basalt fibre reinforced concrete is having improved mechanical properties, durability, and resistance to environmental degradation. These fibres offer comparable tensile strength, superior chemical resistance and thermal stability, making the concrete more durable and resilient in harsh conditions. Additionally, they are environment friendly, aligning well with the sustainable nature of geopolymer concrete, further boosting its appeal for eco-conscious construction projects [12].

2. Experimental Program

Experimental program consists of developing fibre reinforced binary blended geopolymer concrete by using different percentages of basalt fibre and to evaluate its fresh and mechanical properties. The durability studies were conducted on control mix and optimum mix.

2.1 Materials, Mix Proportion and Specimen Preparation

Class F fly ash and GGBFS with specific gravity 2.1 and 2.93 respectively were used as the source materials. A mixture of 12 M sodium hydroxide solution and sodium silicate solution (SiO_2 to Na_2O ratio of 2.2) were used as Alkaline Activator (AA). M-sand with specific gravity of 2.5 and conforming to zone II of IS 383:2016 and 12 mm and 6 mm crushed aggregate with specific gravity of 2.71 and 2.68 respectively and conforming to IS 383:2016 were used as fine and coarse aggregate respectively. A naphthalene-based superplasticizer is used for adjusting the workability. Chopped basalt fibre of 6 mm length having elastic modulus 93 GPa and density 2.6 g/cm^3 is used.

The mix design of M40 grade ambient cured binary blended GPC was done as per the guidelines given in IS 17452:2020. The proportion of source materials (fly ash and GGBFS) used was 60:40 as per literatures [4], [13]. Activator to binder ratio of 0.4, sodium silicate to sodium hydroxide ratio of 2.5 and NaOH solution of molarity 12M is adopted for the study. Superplasticizer dosage of 1.5% of binder were used to get a slump value of 70 to 100 mm. Basalt fibres were added in 0.25, 0.5, 0.75 and 1% volume of concrete. Details of mix proportion obtained are given in Table1. The mix designation BG0, BG0.25, BG0.50, BG0.75 and BG1.00 represents basalt fibre reinforced geopolymer concrete with 0, 0.25, 0.5, 0.75 and 1% of total volume of concrete.

Sodium hydroxide flakes were dissolved in water to get a molarity of 12M and mixed with sodium silicate solution. After 24 hrs of preparation of solution, the source materials and saturated surface dried aggregates were dry mixed and AA and superplasticizer were added and mixed till a homogeneous mix is obtained. Fibres were added slowly to the mix and mixed further. The mix is then checked for workability by conducting slump test. Standard cubes of size 15 cm, cylinders of 15 cm diameter and 30 cm height and prism of size 10 x 10 x 50 cm were prepared by pouring the mix in corresponding mould in 5 cm layers and thoroughly compacting each layer. The prepared specimens were shown in Figure 1.

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Table 1. Mix Proportion

Mix ID	Fiber (%)	FA (kg/m³)	GGBFS (kg/m³)	M-sand (kg/m³)	Coarse aggregate (kg/m³)		NaOH solution (kg/m³)	Sodium silicate solution (kg/m³)
					12 mm	6 mm		
BG0	-	300	200	626.34	695.93	318.93	57.14	142.86
BG0.25	0.25	300	200	626.34	695.93	318.93	57.14	142.86
BG0.50	0.50	300	200	626.34	695.93	318.93	57.14	142.86
BG0.75	0.75	300	200	626.34	695.93	318.93	57.14	142.86
BG1.00	1	300	200	626.34	695.93	318.93	57.14	142.86

Figure 1. Prepared specimen for mechanical and durability properties

2.2 Testing of Specimen

Seven day cured specimens were tested for mechanical properties as per IS 516 (Part 1/Sec 1):2021 and durability characteristics were tested on 28 day cured specimens. Based on the properties, optimum percentage of basalt fibre were fixed. Durability studies like water absorption, sorptivity, thermal conductivity and chemical attack were conducted on optimum mix and is compared with the control mix.

Water absorption test was conducted on cube specimen of 100 mm. Specimens were oven dried and dry weight is measured and is immersed in water for 24 hrs. The wet weight is noted and water absorption is determined as increase in weight by its dry weight, expressed in percentage. Sorptivity tests (ASTM C-1585) were done on cylinder specimen having 100 mm diameter and 50 mm thickness. The sides of the specimen after curing is coated with epoxy resin and the water is allowed to get absorbed through one end only. Weight of the specimen at different time were noted and absorption is calculated. The initial and secondary absorption rate is determined for a time interval of 0 to 6 hrs and 1 to 8 days respectively. Thermal conductivity test was conducted as per thermal needle probe procedure. For inserting needles, holes were drilled in the specimen and a constant current source is provided. The thermal conductivity is determined after heating and cooling stage. Resistance to chemical attack is determined by conducting acid attack, alkaline attack and sulphate attack test. For conducting acid attack test, 28 days cured cubes of size 100 mm is immersed in an acid solution (5% hydrochloric acid of pH 2 is added in water) for 90 days. The resistance to acid attack is determined by the percentage loss in weight of specimen and visual appearance. Alkaline attack test is done by immersing the 100 mm cube specimen in alkaline solution having 5% of NaOH by weight of water and kept for 90 days. The percentage loss in weight is noted after 90 days. Sulphate attack test is conducted on 100 mm cube specimen and are immersed in sulphate solution for 90 days. The solution is prepared by adding 5% of sodium sulphate and 5% magnesium sulphate by weight of water. The percentage loss in strength were determined. Figure 2 shows the different durability tests in specimens.

(a) Specimen in hot air oven (b) Thermal conductivity test (c) Sorptivity test

Figure 2. Durability tests in specimen

3. Results and Discussions

A brief discussion on fresh, mechanical and durability properties of basalt fibre reinforced binary blended ambient cured GPC is discussed in this section.

3.1 Workability

The results of slump test are given in Table 2. From Table, it is observed that as the dosage of fibre increases, the slump value decreased. A fibre dosage of 1% showed a decrease of 40% in slump value compared to control mix. As the fibre content increased, fibres tend to interlock with each other thereby making the concrete mix difficult to flow. At fibre dosage above 0.75%, the fibres clump together in the mix and significantly reduced the workability.

3.2 Mechanical Properties

The compressive strength of specimens at 7th and 28th day are given in Table 2. It is observed that as fibre dosage increased from 0 to 0.5%, the compressive strength increased and beyond 0.5%, there is a decline in strength was observed. Mix BG0.50 showed an increase of 27% in compressive strength compared to control mix. The presence of fibres creates a confining effect on concrete which results in increase in compressive strength. But at higher fibre dosage, fibre turns to form balls, leading to uneven allocation of fibre in the matrix and create weak zones thereby reducing the compressive strength. Compared to control mix, an increase of 23% in splitting tensile strength was observed for mix with 0.5% fibre dosage. Fibres act as bridge across microcracks that develop within the concrete matrix and helps in arresting the crack growth which prevent formation of larger cracks causing failure. The addition of fibres improved ductility and overall tensile capacity of the mix, hence preventing premature failure of concrete due to tensile stress. From Table 2, it is observed that an increase of 28% in flexural strength is obtained for mix with 0.5% of basalt fibre compared to control mix. But the flexural strength decreased when fibre content increased to 0.75%. By considering, workability and mechanical properties, mix BG0.50 is taken as optimum mix and is used for durability studies.

Table 2. Fresh and hardened properties of mix

Mix ID	Slump (mm)	Compressive strength (N/mm^2)		Splitting Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)
		7th day	28th day		
BG0	85	49.33	51.77	4.99	5.19
BG0.25	80	51.65	52.74	5.09	5.98
BG0.50	76	62.31	65.92	6.13	6.65
BG0.75	63	50.96	53.62	4.98	5.21
BG1.00	51	41.95	44.88	4.05	4.73

3.3 Durability Characteristics

Water Absorption. The results of water absorption test are given in Table 3. Comparing the water absorption of mix BG0.50 with control mix, it is seen that a 28% reduction in the water absorption is obtained for optimum mix. The main reasons fibre addition reduces water absorption in concrete are because fibres increase concrete's overall density, lower its porosity and lessen the chances that microcracks would form. These enhancements result in a material that is less prone to water infiltration and more impermeable.

Thermal Conductivity. The thermal conductivity values of control mix and optimum mix are given in Table 3. From Table, it is clear that mix BG0.50 had 60% decrease in conductivity compared to optimum mix. From literatures, it was found that conductivity values of conventional concrete ranges between 0.6 to 3.3 W/mK and addition of natural and synthetic fibres reduced the conductivity to 0.14 to 0.2 W/mK [14], [15]. Similar trend was observed by the addition of basalt fibres in GPC where the conductivity value reduced from 0.04 to 0.016 W/mK. Basalt fibres have lower thermal conductivity, thereby reducing overall thermal conductivity of the composite material. The thermal conductivity value of basalt fibre reinforced geopolymer concrete is low, which thereby helps in reducing energy required for operating building.

Sorptivity. The initial and secondary absorption rate of specimen are given in Table 3. From Table 3, it is observed that both initial and secondary absorption rate decreases as the fibre is being added into the mix. Mix BG0.50 showed a decrease of 14% and 13% of initial and secondary rate of absorption compared to control mix. This reduction in absorption is due to improved micro structure due to addition of fibres in the mix. Figure 3 shows the plot of absorption v/s root time for initial and secondary absorption.

Table 3. Results of durability test

Mix ID	Water Absorption (%)	Thermal Conductivity (W/mK)	Initial Rate of Absorption (mm/√s)	Secondary Rate of Absorption (mm/√s)
BG0	0.198	0.040	3.33×10^{-6}	1.77×10^{-6}
BG0.50	0.142	0.016	2.87×10^{-6}	1.53×10^{-6}

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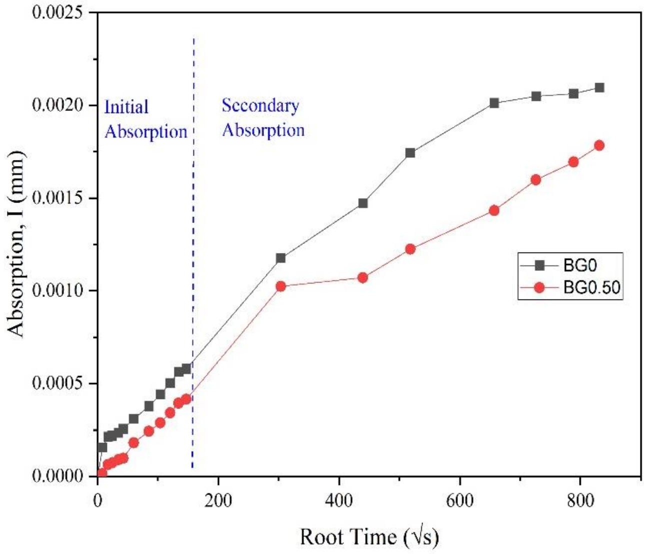

Figure 3. Results of sorptivity test

Chemical Attack. The percentage loss in weight after acid, alkaline and sulphate attack are shown in Table 4. From the Table 4, it is observed that as the fibres were introduced, there is a reduction in percentage weight loss of 35%, 50% and 60% compared to control mix when specimens were subjected to acid, alkaline and sulphate environment. There was no sign of surface erosion found on basalt fibre reinforced GPC as shown in Figure 4. Basalt fibre-reinforced concrete exhibits good chemical resistance primarily due to the inherent chemical inertness of basalt fibres, their ability to reduce the permeability of the concrete matrix and their effectiveness in minimizing micro-cracks. These factors combine to create a concrete that is more resistant to chemical attacks, making it suitable for use in harsh and aggressive environments [6].

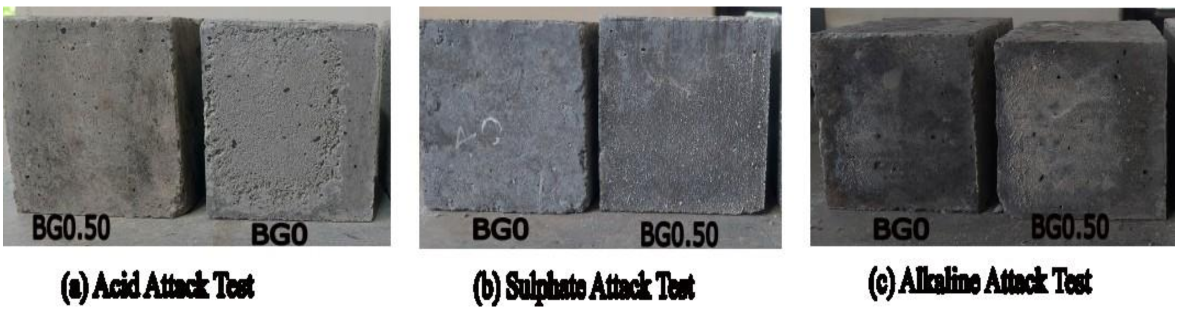

Figure 4. Specimen after chemical attack test

Table 4. Results of chemical attack test

Mix ID	Acid Attack Test	Alkaline Attack Test	Sulphate Attack Test
	% loss in weight	% loss in weight	% loss in weight
BG0	1.004	0.901	1.968
BG0.50	0.646	0.446	0.783

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4. Conclusions

The present study aimed to investigate the effect of basalt fibre in ambient cured binary blended geopolymer concrete. Based on the experiments conducted on specimen, it was observed that as the fibre content increased from 0 to 0.5%, the workability decreased by 11%. Addition of basalt fibres up to 0.5% of volume showed an increase in compressive strength by 27%, splitting tensile strength by 23% and flexural strength by 28% and further addition leads to decrease in strength. The optimum basalt fibre dosage for binary blended GPC lies between 0.5% and 0.75% by volume of concrete. Water absorption, sorptivity, thermal conductivity and weight loss due to acid, alkaline and sulphate exposure for 90 days were decreased by fibre addition. Therefore, addition of basalt fibre enhances durability characteristics. Hence basalt fibre reinforced ambient cured binary blended geopolymer concrete can be considered as sustainable and energy efficient construction material.

Conflict of Interest

The authors assert that they have no known conflicts of interest, financial or personal, that could have influenced this research.

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