Journal of Harbin Engineering University
ISSN: 1006-7043
Vol 44 No. 12
December 2023

Optimizing Geopolymer Concrete: Evaluating the Use of Sugarcane Bagasse-Ash and Carbon Fiber Reinforcement

Gururaj M.H [1], Naresh Kumar B.G[2], Ravi Kiran.L[3]
[1*, 3] Assistant Professor , Department of Civil Engineering, Maharaja Institute of Technology Mysore – 571477, Karnataka, India.
[2] Professor, Department of Civil Engineering, Maharaja Institute of Technology Mysore – 571477, Karnataka, India.

Abstract. Geopolymer Concrete (GPC) has emerged as a viable alternative to traditional cement concrete due to its potential for reducing carbon emissions and promoting sustainability. This study explores the use-of sugarcane bagasse ash (SCBA), a by-product with pozzolanic properties and disposal challenges, in producing GPC. By varying the molar concentration of sodium-based alkali activators and maintaining a constant proportion of carbon fiber, the feasibility of partial replacement of cement by SCBA was examined. Strength tests were conducted at SCBA replacement levels of 5.00%, 10%, 15% & 20%, revealing that the concrete's compressive strength increased up to a 15% SCBA replacement, beyond which strength decreased. Notably, the concrete exhibited superior early strength with 15% SCBA, although later-age strength was influenced by ambient temperature variations. The study also assessed the impact of heat curing on the basic properties of GPC, comparing ambient-cured and heat-cured samples. Results indicated minimal strength variation due to heat curing. The research highlights the economic and environmental advantages of using SCBA over traditional Portland cement, given the latter's significant carbon footprint and resource consumption. Additionally, the investigation of carbon fiber reinforcement and its interaction with SCBA-based GPC offers insights into optimizing its mechanical properties and cost-effectiveness. This study underscores GPC's potential as a sustainable construction material, contributing to reduced greenhouse gas emissions and efficient waste utilization.
Keywords. Carbon fiber, sodium silicate, sodium hydroxide, Geopolymer Concrete, Sugar Cane Bagasse Ash (SCBA).

1. Introduction

Concrete, the most extensively used man-made construction material globally, has seen significant advancements in sustainability with the introduction of geopolymer concrete (GPC). Unlike traditional concrete, which relies on cement, GPC is produced using alternative cementitious materials and a polymerization process, which significantly reduces its carbon footprint. The foundational work on geopolymer technology began in 1957 when Glukhovsky proposed a hypothesis linking alkalis to cementitious materials, paving the way for what were initially known as "alkaline cements." Later, in 1988, Davidovits discovered an alkaline activator liquid that could react with geological by-products such as fly-ash and rice husk-ash to create new binders, coining the term "geopolymer" for these materials. This innovation has positioned GPC as a compelling alternative to Ordinary Portland-Cement (OPC), gaining consideration for its potential to offer superior performance with reduced environmental impact.

Recent advancements in sustainable construction have highlighted the use of waste materials to develop lightweight geopolymers. With the rapid growth of agriculture generating large quantities of agricultural waste, such as sugarcane bagasse ash (SCBA), which poses environmental disposal challenges when buried in landfills, incorporating such materials into cementitious mixtures has emerged as a viable solution. SCBA has been shown to enhance the performance of concrete, serving as an effective supplementary cementitious material and allowing for up to a 20% of cement replacement in concrete mixes with improvements in strength and performance, particularly at up to a 15% replacement level. This study investigates the impact of adding SCBA and carbon fiber to geopolymer concrete, conducting tests on samples with various SCBA replacement percentages (5%, 10%, 15%, and 20%) and a constant carbon fiber content. The findings indicated that compressive strength improved with up to 15% SCBA replacement but declined at higher levels. Moreover, while the early-age strength of SCBA-based geopolymer concrete was superior, it was influenced by ambient temperature variations, affecting later-age strength. The study also explored ambient curing methods for geopolymer concrete, noting that although heat curing remains preferred for its effectiveness, advances in curing techniques could enhance the feasibility of in-situ casting for broader construction applications.

2. Materials and Methods

2.1 Materials

Sugarcane Bagasse Ash: Sugar Cane Bagasse procured from Pandavapura Sahakara Sakhare Karkhane Ltd. (PSSK Ltd). Bagasse ashes (BA) were prepared by burning raw bagasse in 300–750°C for 1–2 hours. They calcinated bagasse at a controlled temperature from 300 °C to 750 °C for 1–2 hours after the bagasse was dried at 100 °C for 24 hours & used in the present study as a partial replacement of cement.

Table 2.1: Specific Gravity Test on Bagasse Ash

Particulars	Obtained value
Sp. Gr. of Bagasse Ash	2.33

Normal Consistency of Bagasse Ash

The standard consistency of a cement paste is defined as the consistency that allows the Vicat plunger to penetrate to a depth of 5 to 7 mm from the bottom of the Vicat mold. To determine the initial and final setting times, soundness, and compressive strength of cement, it is essential to accurately measure the amount of water mixed with the cement for each test.

The experiment conducted on Normal consistency test on Bagasse ash.

Mass of dry cement = 400 gm (85% C-15% B)

Table 2.2: Normal Consistency of Bagasse Ash

SL NO	% of water added	Amount of water added	Needle from bottom in
1	36	144	28
2	38	152	23
3	40	160	15
4	42	168	6

Consistency of bagasse ash under normal condition = 42%

Chemical configuration of Bagasse ash:

Bagasse ash, a byproduct of burning sugarcane bagasse, has a complex chemical composition characterized primarily by high levels of silica (SiO_2), which typically constitutes the largest proportion of the ash. It also contains notable amounts of calcium oxide (CaO), potassium oxide (K_2O), and magnesium oxide (MgO). The existence of these oxides, along with negligible elements such as phosphorus, sodium, and trace metals, influences its potential uses in agriculture as a soil amendment or in construction, cement is partially replaced. The specific proportions of these elements can vary based on factors like the burning conditions & characteristics of the bagasse itself. Understanding this composition is crucial for optimizing the beneficial applications of bagasse ash and mitigating any potential environmental impacts.

Table 2.3: Chemical Composition of Bagasse ash

Oxides Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	MgO	MnO	K_2O	LOI
Sugarcane Bagasse Ash	51.87	4.03	2.58	13	1.14	3.49	0.09	3.98	18.37

Fineness of Bagasse Ash by sieve analysis:

The fineness of bagasse ash, determined by sieve analysis, is a critical factor affecting its suitability for various applications. Sieve analysis measures the distribution of particle size of the ash, indicating how well it can be integrated into other materials, such as in construction or soil improvement. Generally, bagasse ash tends to have a relatively fine particle size, which is advantageous for enhancing properties like the strength & the durability of concrete when used as a supplementary cementitious material. Finer particles typically improve the workability and bonding characteristics of concrete mixtures. Conversely, a higher proportion of coarser particles can reduce the effectiveness of bagasse ash in these applications. Accurate sieve analysis ensures that the bagasse ash meets specific standards for particle size distribution, thereby optimizing its performance and utility. This test performs by considering bagasse ash which is sieved in 90-micron sieve considered according to IS 4031-Part-1 1996.

Weight of bagasse ash taken, W1= 500 gm

Finess = Weight of sample retained on 90micron sieve
Weight of sample originally taken

Table 2.4: Finess of Bagasse ash

SL	Wt. of BA- gm	Wt. of BA retained, gm	fineness (cm^2/g)	Avg. fineness
1	500	20	4.10	4.25
2	500	22	4.40	

Fineness of Bagasse ash = 4.25 (Which less than 10 According to IS 4031Part-1 (1996)

2.2 Carbon Fiber:

In this experimentation we were used carbon-fiber from Coimbatore, Tamilnadu for developing GPC. Carbon fiber reinforced polymer (CFRP) is a composite material made up of carbon-fibers and a polymer matrix. The carbon fibers provide strength and stiffness, while the polymer serves as a cohesive matrix that protects and binds the fibers together. CFRP is produced in various forms, including strips, bars, and sheets, using production techniques such as filament winding, pultrusion, and hand lay-up processes. CFRP materials possess good rigidity, high-strength, low-density, corrosion resistance, vibration resistance, high ultimate strain, high fatigue resistance, and low thermal conductivity. They are bad conductors of electricity and are non-magnetic

Carbon fiber is a high-strength material composed primarily of carbon atoms arranged in a crystalline structure. Its chemical composition is predominantly carbon, often exceeding 90% by weight. The material typically contains a small percentage of other elements, including:

1. **Carbon (C)**: Usually the major component, making up more than 90% of the fiber. The carbon atoms are organized in a planar, hexagonal lattice, contributing to the material's high tensile strength and stiffness.
2. **Hydrogen (H)**: Present in minute quantities, generally less than 1%. Hydrogen atoms are often part of the polymer matrix or sizing agents used in the fiber's production process.
3. **Oxygen (O)**: Also present in trace amounts, primarily as part of surface treatments or sizing agents. The amount is usually less than 1%.
4. **Nitrogen (N)**: Found extremely very small in quantities, often less than 1%, due to its presence in polymer precursors or as part of the fiber's surface treatment.
5. **Other Elements**: Depends on the process of manufacturing and specific application, carbon fiber which contain small amounts of other elements such as silicon (Si) or metals (e.g., iron or aluminium) introduced during production or finishing.

Incorporating carbon fiber into geopolymer concrete can have a prominent outcome on its compressive-strength and overall performance.

- **Enhanced Compressive Strength:** Carbon fibers can improve the compressive strength of geopolymer-concrete by reinforcing the matrix. They provide additional tensile strength and help distribute loads more evenly, which can lead to improved performance under compression.
- **Crack Resistance:** The addition of carbon fibers can reduce the formation and propagation of cracks in geopolymer concrete. This is because the fibers help to bridge cracks and

distribute stresses more uniformly, which can indirectly enhance compressive strength by preventing the development of weaknesses.

- **Durability and Toughness:** Carbon fiber reinforcement can increase the toughness and durability of geopolymer concrete. Although this doesn't directly translate to higher compressive strength, it does contribute to the material's overall structural integrity and longevity. The Table.2.2 shows the basic properties of carbon fiber.

Table 2.5: Properties of carbon fiber

Length (mm)	Diameter (mm)	Tensile strength, MPa	Tensile modulus, GPa	Density, kg/m^3
8	0.18	3447	0.20	1800

2.3 Aggregate:

The fine aggregate collected in the study is locally available M-sand in dry condition. And the coarse-aggregate used in this study is of 20mm, 12mm and 6 mm in size with surface saturated dry conditions.

(a) Coarse aggregate **(b) Fine aggregate** **(c) Carbon fiber**

(d) Raw Bagasse **(e) Bagasse ash**

(f) Alkaline Liquid **(g) Super plasticizer** (Conplast SP-430)

Figure 1. Ingredient materials for GPC mixes

3. Mix proportion

Based on information of B.V. Rangan some simple guidelines for the design of heat cure low-calcium fly-ash based geopolymer concrete, mix design of Bagasse ash-based GPC is proposed. According to B.V. Rangan the combined aggregate may be taken between 75% and 80% of the mass of GPC. The compressive strength & the workability of fresh concrete mainly depend on the Alkaline-liquid to Cementitious material ratio, water to geopolymer solid ratio, wet mixing time, heat curing temperature and heat curing time. He has suggested alkaline liquid to Cementitious material ratio by-mass value should range of 0.30 to 0.45 are recommended (B V Rangan approach). The wet mixing should be done for a time of four minutes and oven curing at a temperature of 60° C for 24 hours. Sodium-silicate and sodium-hydroxide is cheaper than potassium silicate and potassium hydroxide. Commercially available sodium silicate solution A53 with SiO_2:Na_2O ratio by mass of around 2, i.e. SiO_2=29.4% Na_2O=14.7% and water of 55.9% by mass, and 97% - 98% sodium hydroxide solids were recommended. Based on the above aspects mix design was done and the quantity of materials to be procured was determined and the below Table 1. gives us the basic values to be considered for the mix design, trail mix has been done and finally arrive with the proper mix proportion which gives good workability and physical appearance to the geopolymer concrete. In the present study to design the mix proportion ratio of Na_2SiO_3 to NaOH was fixed as 2.50, and Molarity of NaOH considered as 12M. In this study the carbon fiber of 0.2% of weight of the cementitious materials has taken for the preparation of GPC mix. The length of the carbon fiber considered for the mix was 25 mm. Alkaline: liquid to binder ration is of 0.3, amount of super plasticizer considered is 2% of amount of cementitious material.

Table 3.1: Typical range of values as suggested by B V Rangan for trial mix of GPC

Alkaline liquid / fly ash	Water/geopolymer solids	Workability
0.30	0.165	Stiff
0.35	0.190	Moderate
0.40	0.210	Moderate
0.45	0.230	High

Table 3.2: Geopolymer concrete mix proportion

Materials	Coarse Aggregate (kg/m^3)			Fine Aggregate (kg/m^3)	Cementitious material (kg/m^3)	Na_2SiO_3	NaOH (12 M)	Super plasticizer
Mass Kg/m^3	15% of 20 mm	20% of 12 mm	35% of 6 mm	30%	424.615	84.615	42.462	8.492
	277.20	369.60	646.80	554.40				

The workability of Geopolymer Concrete for a Na_2SiO_3 to NaOH ratio was maintained as 2.0 and M20 grade concrete is measured using slump and the values are as follows.

Table 3.3: Slump values for BA based Geopolymer concrete

Mix	Controlled	5% BA based GPC	10% BA based GPC	15% BA based GPC	20% BA based GPC
Slump in mm	110	70	80	90	88

4. Methodology

4.1 Preparation of alkaline liquid

The alkaline solution is active as the silica and aluminium dissolve. As a result, a significant amount of heat is generated and released. In this study, Sodium-Silicate solution and Sodium-Hydroxide solution are combined to create an alkaline liquid. Just standard solution form of sodium silicate solution is available; it was purchased from a small-scale industry in Bangalore.

The molecular weight of one mole of sodium hydroxide, which is accessible as flakes, pellets, etc., is 40gm. The solution for one mole of sodium hydroxide was prepared for a 12-molar mass of solid, depending on the attention of solution that is needed. As a result, we require 480 gm of NaOH pellets for every 12 moles of NaOH. A sodium hydroxide solution with 12 M is produced when the 480 grams of NaOH pellets are dissolved in 1000 ml of water.

A significant amount of heat is released during making the sodium hydroxide solution. In order to prepare the solution, we must stir it continuously in a water bath. Sodium-silicate solution and sodium-hydroxide solution are continuously combined after 15 minutes of NaOH solution preparation. After that, the produced solution is left to cool for 24 hours in a water bath.

Figure 4.1. Preparation of alkaline liquid

4.2 Mixing of Geopolymer-Concrete (GPC)

Bagasse ash, sand, and aggregate were mixed for 60 seconds during mixing before carbon fibres and methylcellulose were added & mixed for two more minutes. The mix is carried out in two steps one is dry mix and the other is wet mix. The capacity of pan mixer is 80 litres per trial i.e. a maximum of either 3 cubes of concrete or 3 cylinders of concrete can be casted.

In the dry mix first all the dry materials are added and dry mix prepared for not less-than 2 min. Once the uniform colour and mixture occurs, alkaline liquid is added, that was prepared 24 hours earlier and then super plasticizer is added. Just after the addition of super plasticizer 35-40% of water by the cement weight is added & mix is continued for 3 – 4 mins.

4.3 Casting and Curing of GPC (Geopolymer concrete)

Once the mixing is done, the specimen moulds (cubical moulds of size 150x150x150 mm) (cylindrical moulds of 150 x 300 mm) were filled in layers with concrete mix and compacted. Compaction is done using table vibrator and specimen kept is demoulded after 24 hours. Specimens were kept for 1 day curing under normal room temperature.

Then the specimens are kept in oven for 3 days and later the specimens are kept for ambient curing for 7 and 28 days. The curing temperature will also influence the strength of GPC. In GPC, the chemical reaction initiates the polymerization process, which continues through the curing stage. The specimens are then allowed to cure at ambient temperature.

Figure 4.2. Casting and curing process

5. Results and Discussions

Experimental investigations have been conducted to assess the behavior and mechanical properties of geopolymer concrete made with partial replacement of bagasse ash. This includes the experimental work, properties of material, concrete mix and testing of specimen.

To accomplish the purpose of the present study the experimental work is carried on 68 numbers of specimens. In which 12 are cubes and 12 are cylinders for partially replacement of cement with bagasse ash and 8 (4 cubes +4 cylinders) are M20 grade conventional concrete specimens. A study takes place on comparison of mechanical properties and strength properties of GPC with partial replacement of bagasse ash of M20 grade with conventional concrete. The percentages of bagasse ash replaced with cement are 5%,10%, 15% and 20% by the weight of cement.

5.1 Test Results on Compressive-Strength Test

Cubes of size 150 x 150 x 150 mm were cast for compressive strength testing at 7, 14, & 28 days, with bagasse ash (BA) replacements of 5%, 10%, 15%, and 20%, while maintaining a constant 0.20% carbon fiber (CF) content. The optimal BA replacement was identified, and the strength results are presented in Table 5.3 & Table.5.4 and Figure5.2 & Figure.5.3. The compressive-strength of GPC with 10% BA showed a 13.28% increase compared to GPC with 5% BA. Furthermore, GPC with 15% BA exhibited a 21.83% increase in compressive strength compared to GPC with 10% BA. However, a 20% BA replacement resulted a decrease in strength. This indicates that the optimal BA dosage for GPC is 15% by weight of cementitious material.

Compressive-Strength of Carbon-Fiber Reinforced Geopolymer Concrete

Understanding the impact of carbon:fiber when mixed with Geopolymer concrete (GPC) is crucial in studying its compressive strength. Table 4 below highlights the optimal carbon fiber replacement for the production of GPC.

Table 5.1: Typical Ranges of CF

Carbon FiberContent (%)	Expected Effect on Compressive Strength	Typical Range
0.10	Neutral to slight increase	+1% to +3%
0.20	Neutral to slight increase	+2% to +5%
0.30	Neutral to slight decrease	-5% to +5%
0.40	Potential decrease	-5% to -10%
0.50	Noticeable decrease	-10% to -15%

o 0.10% Carbon Fiber: At this low concentration, the impact on compressive strength is generally neutral or shows a slight increase, with a typical range of +1% to +3%. This suggests that a minimal amount of carbon fiber may offer a small benefit without significant changes in strength.

○ 0.20% Carbon Fiber: Increasing the carbon fiber content to 0.20% continues to show a neutral to slight increase in compressive strength, with a range of +2% to +5%. This amount seems to enhance strength moderately, possibly due to better reinforcement and stress distribution.

○ 0.30% Carbon Fiber: At this intermediate level, the effect becomes more variable. The compressive strength may either slightly increase or decrease, ranging from -5% to +5%. This shows that some improvements might be observed, the impact could also be negative, potentially due to issues such as poor fiber dispersion or interaction with the geopolymer matrix.

○ 0.40% Carbon Fiber: With 0.40% carbon fiber content, there is potential decrease in compressive strength, with a range of -5% to -10%. The decrease might be attributed to an excess of fibers disrupting the concrete's cohesiveness or creating weaknesses within the mix.

○ 0.50% Carbon Fiber: At this higher concentration, there is a perceptible decrease in compressive strength, with a reduction ranging from -10% to -15%. This recommends that too much carbon fiber can have a detrimental effect, likely due to poor mixing, increased fiber clumping, or a weakened matrix.

Table 5.2: Test Result on Compressive Strength on Carbon Fiber

Percentage of CF (%)	0.10	0.20	0.30	0.40	0.50
Compressive Strength (MPa)	23.45	26.78	25.26	23.18	21.88

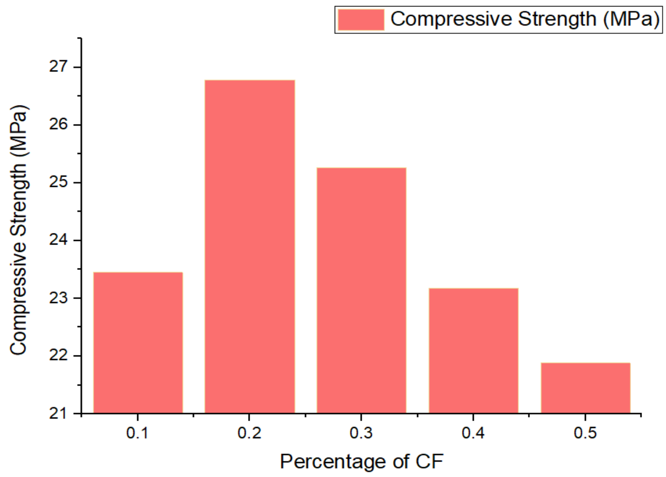

Fig 5.1: Test result on Compressive-Strength at different percentage of CF

Table 5.3: Compressive Strength Test results at different % of BA and CF

Compressive Strength of Cubes, MPa			
Mix	**7 days'**	**14 days'**	**28 days'**
5%BA +0.2% CF	10.98	12.56	14.23
10%BA +0.2% CF	11.26	14.18	16.12
15%BA +0.2% CF	14.92	15.65	19.64
20%BA +0.2% CF	11.88	13.29	16.18

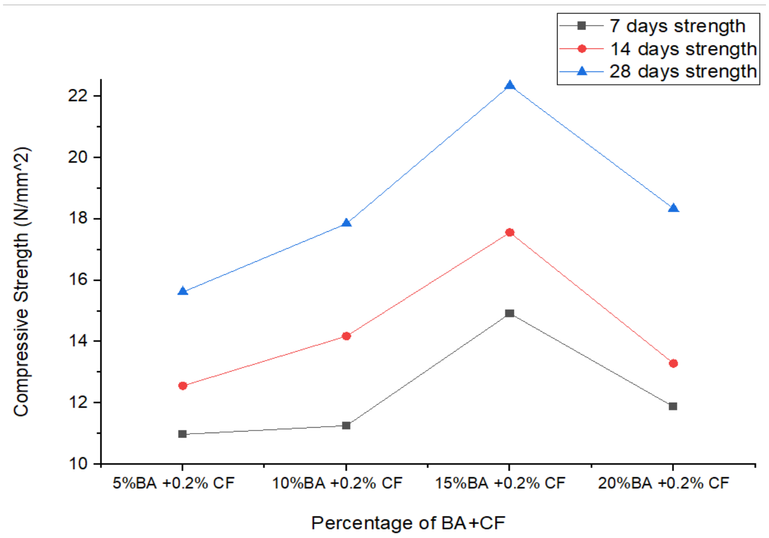

Figure 5.2. Compressive strength of GeoPolymer Concrete at different % of BA and CF

Table 5.4: Compressive Strength Test results for typical GPC mixes

Compressive: Strength of Cubes, MPa			
Mix	**7 days**	**14 days**	**28 days**
5	18.81	19.83	25.64
10	20.83	22.62	24.89
15	22.56	28.67	31.54
20	13.92	19.50	21.45

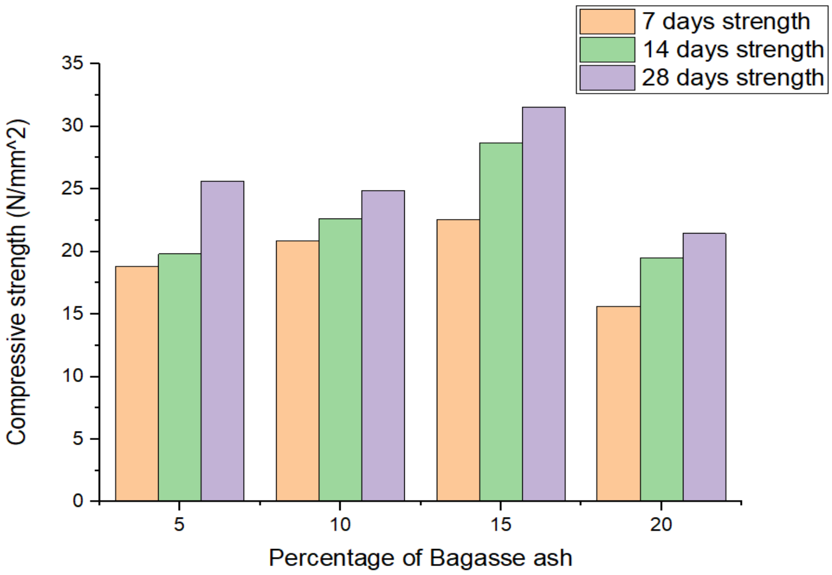

Figure 5.3. Compressive strength of GPC at different % of BA

5.2 Test Results on Split-tensile Strength Test

The cylinders were prepared for split-tensile strength testing of M20 grade concrete at 7 days, 14 days , and 28 days, using bagasse-ash replacements of 5%, 10%, 15.0% & 20%, with a constant 0.2% carbon fiber (CF) content. The strength results are detailed in Table.5.7 & Table.5.8 and Figure 5.5 & Figure.5.6.

The compressive-strength of geopolymer concrete (GPC) with 10% BA showed 38.15% increases in associated to GPC with 5% BA, and the tensile-strength of GPC with 15% BA increased by 42% compared to GPC with 10% BA. However, further increasing the BA content to 20% resulted in a reduction in strength parameters. This indicates that the optimal BA dosage for GPC is 15% by weight of cementitious material.

5.2.1 Split Tensile Strength of Carbon-Fiber Reinforced (CFR) based Geopolymer Concrete.

The split: tensile strength of Carbon Fiber Reinforced Geopolymer Concrete (CFRGC) is an important parameter for understanding the material's performance, particularly its ability to resist tension.

Adding carbon fibers to this mix enhances its mechanical properties, which includes tensile strength. In Split Tensile strength is used to different percentage and typical range of CFRP in below table 4.5.

Table 5.5: Typical Ranges on CF

Carbon FiberContent (%)	Expected Effect on Compressive Strength	Typical Range
0.10	Slight increase	+05% to +10%
0.20	Noticeable increase	+10% to +20%
0.30	Moderate increase	+20% to +40%
0.40	Significant increase	+40% to +60%
0.50	High increase	+60% to +80%

- 0.10% Carbon Fiber: At this low level, the compressive strength shows a slight increase, ranging from +5% to +10%. This suggests that even a minimal amount of carbon fiber can provide a modest boost to the material's strength.
- 0.20% Carbon Fiber: With a 0.20% addition, there is a noticeable increase in compressive strength, ranging from +10% to +20%. This indicates a more pronounced benefit, likely due to improved fiber reinforcement and stress distribution within the concrete matrix.
- 0.30% Carbon Fiber: At this intermediate level, the strength increase becomes moderate, with a range of +20% to +40%. This substantial improvement reflects the effectiveness of carbon fibers in enhancing the concrete's load-bearing capacity and overall performance.
- 0.40% Carbon Fiber: Increasing the content to 0.40% results in a significant boost, with compressive strength increasing by +40% to +60%. This significant enhancement suggests that at this concentration, carbon fibers are highly effective in reinforcing the geopolymer concrete.

- 0.50% Carbon Fiber: At the highest concentration listed, the compressive strength sees a high increase, ranging from +60% to +80%. This specifies that a higher carbon fiber content can lead to remarkable improvements in strength, demonstrating the potential for improved performance with optimal fiber usage.

Table 5.6: Result on Split-Tensile Strength on CFRP

Percentage of CF (%)	Split Tensile Strength (Mpa)
0.10	2.85
0.20	3.57
0.30	4.03
0.40	4.65
0.50	5.27

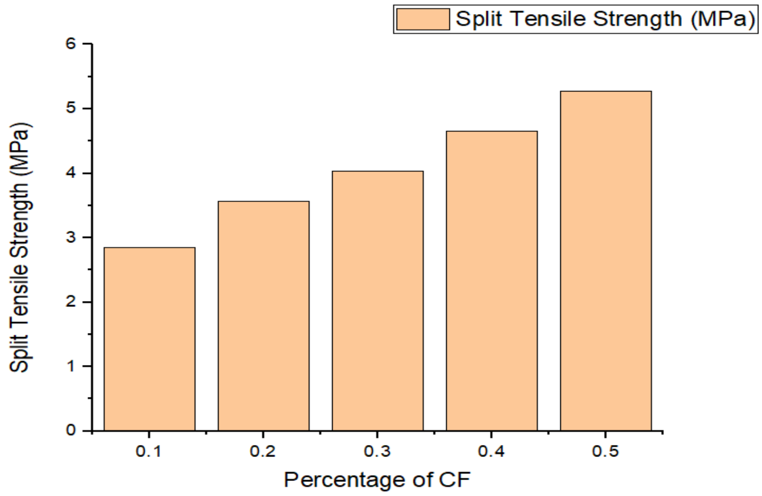

Figure 5.4. Test result on Compressive Strength at different percentage of CF

Table 5.7: Split Tensile Strength Test results at different % of BA and CF

Split tensile Strength of Cylinders, MPa			
Mix	**7 day-s**	**14 day-s**	**28 day-s**
5%BA +0.2% CF	1.19	2.05	2.4
10%BA +0.2% CF	1.58	2.56	2.91
15%BA +0.2% CF	2.48	3.2	3.62
20%BA +0.2% CF	1.38	2.41	2.61

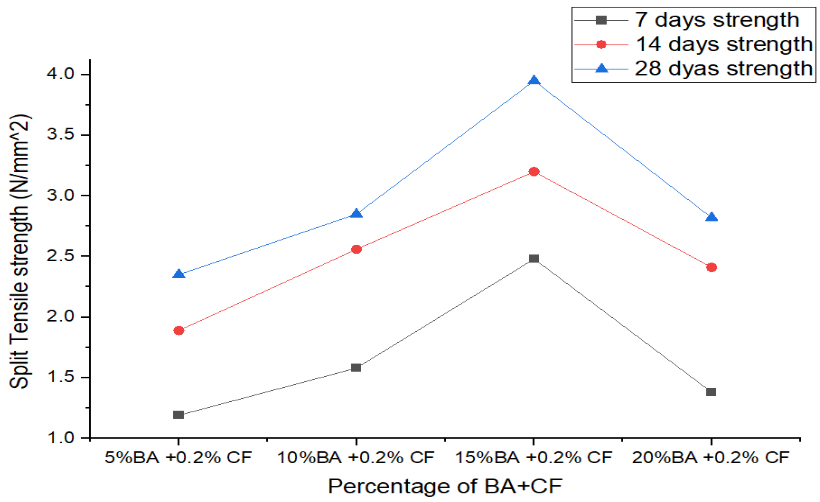

Figure 5.5. Split Tensile strength of Geopolymer concrete at different % of BA and CF

Table 5.8: Split Tensile Test results at different % of BA

Split Tensile of cylinders MPa			
Mix	**7 days**	**14 days**	**28 days**
5	1.54	1.76	2.08

10	2.27	2.56	2.16
15	2.45	2.89	3.12
20	1.75	2.27	2.56

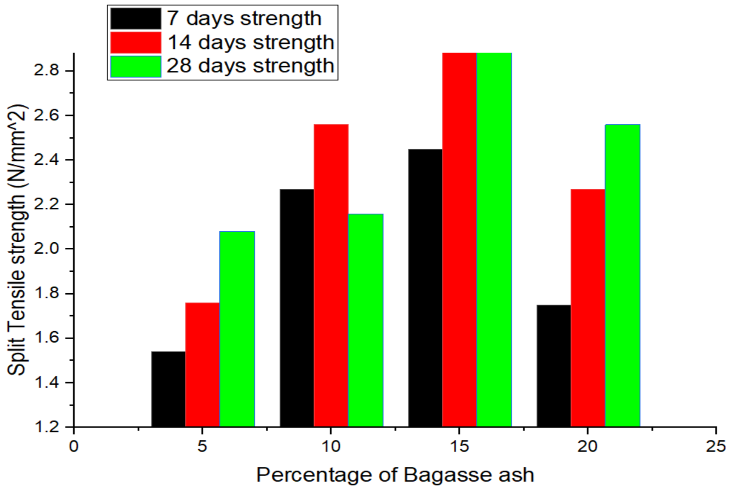

Figure 5.6. Split Tensile strength of GPC for the different percentage of BA

6. Results and Discussions

The experimental investigations has been carried out to determine the behaviour and the mechanical properties of bagasse-ash based geopolymer-concrete with partial replacement of bagasse ash. This includes the experimental work, properties of material, concrete mix & testing of specimen.

To achieve the objectives of this study, experimental work was conducted on specimens, including cubes and cylinders, to partially replace cement with bagasse ash in M20 grade conventional concrete. The study focuses on comparing the mechanical properties and strength of geopolymer concrete (GPC) with different levels of bagasse ash replacement (5%, 10%, 15%, and 20% by weight of cement) to those of conventional M20 grade concrete.

7. Conclusions

In this investigation the physical properties and hardened-properties of carbon fiber reinforced, bagasse ash-based Geopolymer-concrete were studied with properties of normal concrete. Based on the test results, the following conclusions can be made:

- The workability of geopolymer: concrete (GPC), as indicated by slump values, decreases as the percentage of bagasse ash (BA) increases from 5% to 20%. This tendency suggests that higher BA content reduces the workability of the mixture. However, a minor improvement in workability is observed when increasing BA from 15% to 20%.
- The reduction in workability with increasing BA content is attributed to the fibrous nature of bagasse ash, which absorbs water from the concrete, leading to a harsher mix.
- The strength properties of GPC improve with the bagasse ash addition up to a 15% replacement level. Beyond this point, further increases will result in diminishing returns in strength, likely due to the carbon content and fibrous characteristics of the ash.
- The partial replacement of cement with bagasse ash in M20 grade concrete has a significant impression on the mechanical and strength properties of GPC. Varying the levels of BA replacement (5%, 10%, 15%, and 20%) demonstrates that certain proportions can lead to optimal strength improvements compared to conventional M20 grade concrete.
- The study underscores the latent of bagasse

ash as a sustainable and effective supplementary cementitious material, capable of enhancing the properties of GPC.

- GPC containing 15% bagasse ash shows excellent early strength, likely due to controlled curing temperatures during the initial days, although later-age strength is less pronounced.
- The inclusion of carbon fiber, at a fixed percentage of 0.20% by weight of cement, contributes to the strengthening and toughening of GPC, resulting in substantial improvements in compressive strength.

References

[1] Davidovits, J. “High-Alkali Cements for 21st Century Concretes”. ACI Special Publication, P.N-144, 1994.

[2] J. Davidovits, Geopolymer Chemistry and Applications, 3rd edition, 2011.

[3] M. Khan , M. Ali , “Improvement in concrete behavior with fly ash, silica - fume and coconut fibres “. Construct. Build. Mater. (2019).

[4] H. Sasanipour , F. Aslani , J. Taherinezhad , “Effect of silica fume on durability of self - compacting concrete made with waste recycled concrete aggregates”. Construct. Build. Mater. 227 (2019) 116598.

[5] H. Chol, J. Lee, B. Lee, J. Nam, “Shrinkage properties of concretes using blast furnace slag and frost - resistant accelerator”. Construct. Build. Mater. 220 (2019) 1– 9.

[6] X. Li, J. Liu, J. Qin, Y. Liu, Y. Qu, R. Zhang, “Dissolution behavior of a novel composite fiber made from blast furnace slag”. Construct. Build. Mater. 206 (2019) 442 – 448.

[7] J. Rissanen, C. Giosué , K. Ohenoja , P. Kinnunen , M. Marcellini , M. L. Ruello , F. Tittarelli , M. Illikainen , “The effect of peat and wood fly ash on the porosity of mortar”. Construct. Build. Mater. 223 (2019) 421 – 430.

[8] G. C. Cordeiro, K. E. Kurtis, “Effect of mechanical processing on sugar cane bagasse ash pozzolanicity”. Cement Concr. Res. 97 (2017) 41 – 49.

[9] Sales, S. A. Lima, “Use of Brazilian sugarcane bagasse ash in concrete as sand replacement “. Waste Manag. 30 (2010) 1114 – 1122.

[10] S. Deepika, G. Anand, A. Bahurudeen, M. Santhanam, “Construction products with sugarcane bagasse ash binder”. J. Mater. Civ. Eng. 29 (2017) 4017189.

[11] G. P. Lyra, V. dos Santos, B. C. De Santis , R. R. Rivaben , C. Fischer , E. M. de J. A. Pallone , J. A. Rossignolo , “Reuse of sugarcane bagasse ash to produce a lightweight aggregate using microwave oven sintering “. Construct. Build. Mater. 222 (2019) 222 – 228.

[12] Rajasekar, K. Arunachalam, M. Kottaisamy, V. Saraswathy, “Durability characteristics of Ultra High Strength Concrete with treated sugarcane bagasse ash”. Construct. Build. Mater. 171 (2018) 350 – 356.

[13] P. Jamsawang, H. Poorahong, N. Yoobanpot, S. Songpiriyakij , P. Jongpradist , “Improvement of soft clay with cement and bagasse ash waste”. Construct. Build. Mater. 154 (2017) 61 – 71.

[14] Rerkpiboon, W. Tangchirapat, C. Jaturapitakkul, “Strength, chloride resistance, and expansion of concretes containing ground bagasse ash”. Construct. Build. Mater. 101 (2015) 983 – 989.

[15] B.V Rangan et al. (1996), K.Raja gopal, K.Thangavel, “Evaluation of Bagasse ash as supplementary cementitious material”. Cement and Concrete Composites, Volume 29, No. 6, (1996), 515–524.

[16] M. Z. M. Salleh, W. H. Wan Ibrahim, A. Ismail, M. H. Wan Ibrahim, “Mechanical properties of concrete containing high volume sugarcane bagasse ash and fly ash.” Cement Concr. Compos. 86 (2018) 44 – 52.

[17] S. Sharma, R. Tiwari, “Impact of bagasse ash on the strength and durability of concrete: A review.” J. Build. Eng. 20 (2018) 118 – 131.

[18] R. R. Pedini, S. L. Alcântara, J. B. Barbosa, “Mechanical and microstructural properties of concrete containing sugarcane bagasse ash and recycled aggregates.” J. Mater. Civ. Eng. 30 (2018) 4018063.

[19] N. Bheel, A. Bheel, M. Shaikh, “Sustainable use of sugarcane bagasse ash in concrete: A

review." J. Build. Pathol. Rehabil. 4 (2019) 27 – 35.

[20] V. R. Lertwattanaruk, S. Makul, C. Siripattarapravat, "Utilization of ground bagasse ash as a pozzolanic material in concrete." Constr. Build. Mater. 48 (2013) 582 – 590.

[21] F. U. A. Shaikh, S. W. M. Supit, "Mechanical and durability properties of high-volume fly ash concrete containing bagasse ash." J. Adv. Concr. Technol. 13 (2015) 219 – 227.

[22] S. Aydin, Y. Yardimci, M. Y. Yardimci, "Development of high-performance concrete using fly ash, silica fume, and basalt fiber." J. Clean. Prod. 112 (2016) 742 – 750.

[23] A. P. Fantilli, M. A. Vallini, "Carbonation-induced shrinkage and creep in concrete with fly ash." Cem. Concr. Res. 87 (2016) 21 – 28.

[24] P. Nath, P. Sarker, "Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition." Constr. Build. Mater. 66 (2014) 163 – 171.

[25] A. Deb, P. Nath, P. K. Sarker, "The effects of ground granulated blast-furnace slag blending with fly ash and activator content on the workability and strength properties of geopolymer concrete cured at ambient temperature." Mater. Des. 62 (2014) 32 – 39.

[26] R. Chithra, S. R. Kumar, A. Chinnaraju, "The effect of colloidal nano-silica on workability, mechanical and durability properties of high-performance concrete with copper slag as partial fine aggregate." Constr. Build. Mater. 113 (2016) 794 – 804.

[27] B. Singh, G. Ishwarya, M. Gupta, S. K. Bhattacharyya, "Geopolymer concrete: A review of some recent developments." Constr. Build. Mater. 85 (2015) 78 – 90.