Mechanical and Durability Properties of Glass Fiber Reinforced Geopolymer Concrete: Experimental Investigation

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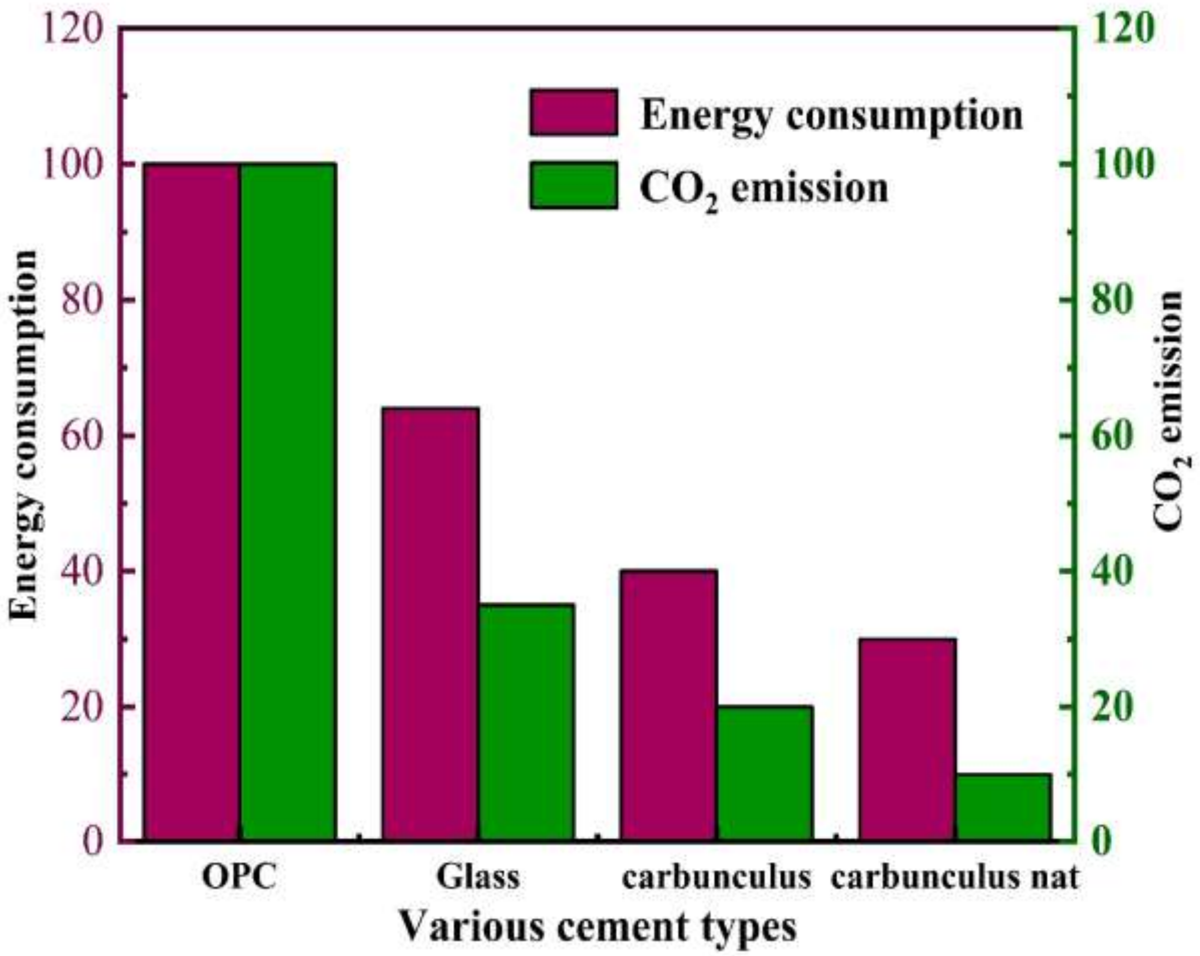
Abstract: Geopolymer concrete (GPC) is a promising alternative to conventional cement-based concrete due to its excellent mechanical and durability properties, low CO2 emissions, and utilization of industrial wastes. However, the brittle nature of GPC limits its structural applications. To overcome this limitation, researchers have investigated the use of fiber reinforcement in GPC. Among the various types of fibers, glass fibers have been extensively studied due to their high strength, stiffness, and corrosion resistance. This paper presents a comprehensive review of the research conducted on glass fiber reinforced geopolymer concrete (GFRGPC). The paper summarizes the recent developments in the field of GFRGPC, including the effects of fiber length, content, aspect ratio, orientation, and surface treatment on the mechanical and durability properties of GFRGPC. The paper also discusses the various characterization techniques used to evaluate the properties of GFRGPC, such as compressive strength, flexural strength, split tensile strength, impact resistance, toughness, and durability under different environmental conditions. The review concludes with an overview of the potential applications of GFRGPC in the construction industry and the challenges that need to be addressed for its widespread adoption.
Keywords: Geopolymer concrete, Glass fibers, Fiber reinforced concrete, Mechanical properties, Durability, Characterization techniques, Applications, Challenges.

Introduction:

Geopolymer concrete (GPC) is a cement-free concrete that is produced by activating the aluminosilicate materials with alkaline activators [1] . GPC has been gaining significant attention in recent years due to its low CO2 emissions, high mechanical and durability properties,[2],[3] and utilization of industrial wastes [4] . However, the brittle nature of GPC limits its structural applications [5] ,[6] ,[7] . To overcome this limitation, researchers have investigated the use of fiber reinforcement in GPC. Among the various types of fibers, glass fibers have been extensively studied due to their high strength, stiffness, and corrosion resistance.[8]

Glass fiber is a common reinforcing material used in conventional concrete and other fiber-reinforced concrete [9] . The use of glass fiber in geopolymer concrete has the potential to further enhance the properties of the material, such as reducing cracking, increasing tensile and flexural strength, and improving impact resistance[10]. While there have been studies on the use of fibers in conventional concrete and other fiber-reinforced concrete, there is limited research on the use of glass fiber in geopolymer concrete[11] . Therefore, there is a need for more comprehensive studies that investigate the effects of glass fiber on the properties of geopolymer concrete[12] .

The research shows that the carbon dioxide emission of geopolymer concrete manufacturing is far lower than that of ordinary Portland cement concrete because the raw materials of geopolymer concrete do not need high-temperature calcination [15,16]. In addition, the energy consumption and CO2 emissions of ordinary Portland cement and geopolymer is shown in Figure 1 [18]. Figure shows that the CO2 emissions and energy consumption of geopolymers are much lower than ordinary Portland cement



The findings of this study could contribute to the development of sustainable and durable construction materials, and provide insights into the effects of fiber reinforcement on the properties of geopolymer concrete.

Objective:

The objective of this paper is to present a comprehensive review of the research conducted on glass fiber reinforced geopolymer concrete (GFRGPC).

- The paper summarizes the recent developments in the field of GFRGPC , including the effects of fiber length, content, aspect ratio, orientation, and surface treatment on the mechanical and durability properties of GFRGPC.
- The paper also discusses the various characterization techniques used to evaluate the properties of GFRGPC, such as compressive strength, flexural strength, split tensile strength, impact resistance, toughness, and durability under different environmental conditions.
- The research concludes with an overview of the potential applications of GFRGPC in the construction industry and the challenges that need to be addressed for its widespread adoption.

Literature Review:

Several researchers have investigated the use of glass fibers as reinforcement in GPC.

- Ahmed et al. (2019) reported that the addition of 1% glass fibers increased the compressive strength of GPC by 26% and the flexural strength by 58%. They also found that the addition of glass fibers improved the ductility and toughness of GPC. Zhang et al. (2018) investigated the effect of fiber length on the mechanical properties of GFRGPC and found that longer fibers resulted in higher flexural strength and toughness. They also reported that the addition of glass fibers improved the impact resistance of GPC.
- Wu et al. (2017) investigated the effect of fiber content on the mechanical properties of GFRGPC and found that the optimal fiber content was 1.5%. They also reported that the addition of glass fibers improved the durability of GPC under freeze-thaw cycles.

- "Mechanical properties and microstructure of glass fiber reinforced geopolymer composites" by Zhu et al. (2016): The study investigated the effect of adding different percentages of glass fiber (0%, 1%, 2%, and 3%) on the mechanical properties and microstructure of geopolymer composites. The results showed that the addition of glass fiber improved the compressive and flexural strength of the geopolymer composites. The microstructure analysis also showed that the glass fiber improved the interfacial bonding between the geopolymer matrix and the aggregate.

- The effect of alkali resistant glass fibres on the compressive, flexural and split tensile strength of various grades of concrete such as M 20, M 30, M 40 and M 50 has been studied by Chandramouli et al (2010). It was observed that glass fibre reinforced concrete shows less permeability of chlorides for higher grade of concrete. A reduction in bleeding is observed by addition of glass fibres in the glass fibre concrete mixes which improves the surface integrity of concrete, improves its homogeneity and reduces the probability of cracks.

- Yeol Choi and Robert L. Yuan (2005) presented an experimental investigation into the relationship between the splitting tensile strength and compressive strength of glass fibre reinforced concrete (GFRC) and polypropylene fibre reinforced concrete (PFRC). The splitting tensile strength and compressive strength of GFRC and PFRC at 7, 28 and 90 days are used. Test results indicate that the addition of glass and polypropylene fibres 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.

- Sekar (2004) investigated the feasibility of using industrial waste fibres in fibre reinforced concrete. Three types of waste fibres collected from three different industries namely lathe, wire winding and wire drawing industries were used in this investigation. Concrete specimens were cast with and without fibres and were tested under compression, split tension and flexure as per relevant Indian Standard Specifications. Test results indicated that addition of waste fibres from lathe and wire winding industries in plain concrete enhances the strength markedly, whereas the inclusion of waste fibres from wire drawing industry decreases the strength of concrete. Also the percentage increase in strength to weight ratio achieved by adding lathe industry waste fibres in plain concrete is higher than those obtained by adding wire winding industry waste fibres.

- "Effect of glass fiber on the mechanical and fracture properties of geopolymer concrete" by Ahmed et al. (2019): The study investigated the effect of adding different percentages of glass fiber (0%, 0.5%, 1%, and 1.5%) on the mechanical and fracture properties of geopolymer concrete. The results showed that the addition of glass fiber improved the compressive and flexural strength of the geopolymer concrete. The fracture toughness and energy absorption capacity of the concrete also increased with the addition of glass fiber.

Experimental Program:

Materials

The material used for making glass fiber reinforced geopolymer concrete are low calcium dry fly ash as source material, alkaline liquid, coarse aggregate, fine aggregate, cement, lime, glass fiber and water.

- Fly ash

Fly ash is a residue of combustion of pulverized coal collected by mechanical or electrostatic separators from the chimney gasses of thermal power plants. The spherical form of fly ash particles improves the flow ability & reduces the water demand. In this experimental work low calcium dry fly ash (Pozzocrete-83) produced from Dirk India limited, Nashik obtained from Ekalahare(Nashik) thermal power station. The fineness of fly ash particle of specific surface was 368 m2/kg.

- Alkaline liquid

A combination of sodium hydroxide and sodium silicate solution was used as alkaline activators for geopolymerization. Sodium hydroxide is available in market in pallet and flakes form. In this experimental study sodium hydroxide flakes with 97% purity of 13 molarity dissolved in distilled water to prepare NaOH solution. Sodium silicate generally available in white viscous solution form uses along with sodium hydroxide. The chemical composition of sodium silicate is Na_2O=14.53%, SiO_2=23.72% (Total Solids = 38.25%), Water
= 61.75%.

- Aggregate

Course aggregate of size up to 20mm having fineness modulus 6.66, bulk density of 1630 kg/m3 and specific gravity of 2.603 were used.Fine aggregate is cleaned dry river sand having specific gravity 2.576 and fineness modulus 3.35 was used.

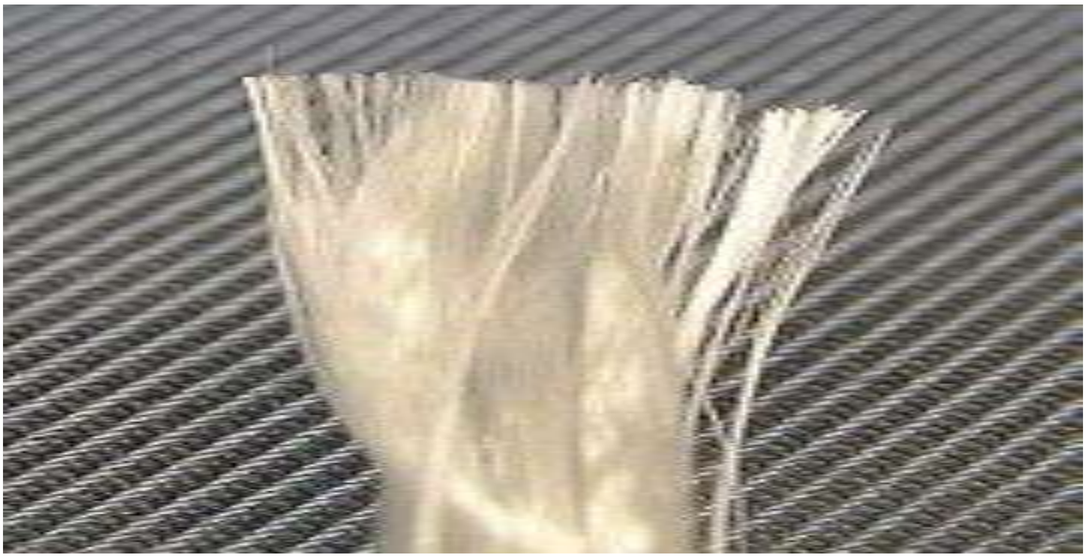
- Cement

Cement used in concrete to replacement of fly ash by 10% to avoid the heat curing limitation in geopolymer concrete. The most common type of cement used is Ordinary Portland cement of 53 grades.

- Lime

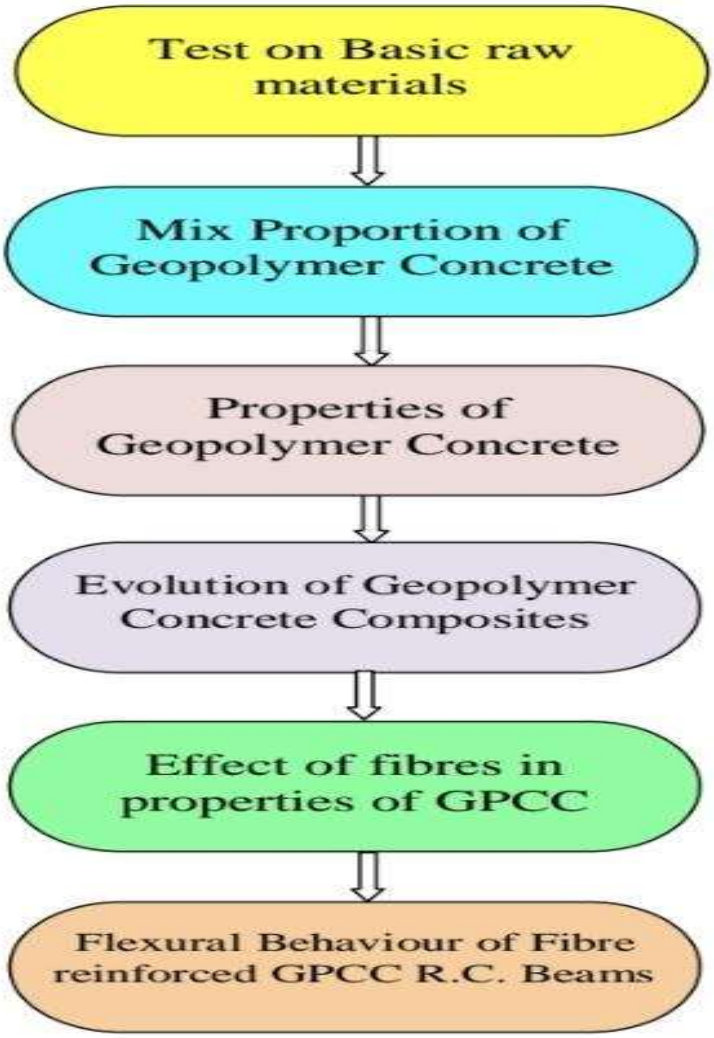
The locally available hydrated lime which generally used as construction material was used for early setting at room temperature. Lime was added in 10% as replacement of fly ash. The lime is a solid composite material having specific gravity 2.7 and bulk density 1425 kg/m3. It comes in solid lump form when convert it to powder form has average particle size of 25micron.

- Glass fiber



Glass fibres are made of silicon oxide with addition of small amount of other oxides Glass fibres are characteristic for their high strength, good temperature resistance, corrosion resistance & available at low price. In this study alkali resistance glass fibre of length 12mm &nominal diameter 14 microns with density of 2680Kg/m3 going to use used the above data provided by supplier.

In this study, six mixtures of GFRGPC were prepared with different fiber lengths, contents, and aspect ratios. The mixtures were cast in cylindrical and rectangular molds, and the specimens were cured at room temperature for 28 days. The mechanical properties of GFRGPC were evaluated by conducting compressive strength, flexural strength, and split tensile strength tests. The impact resistance of GFRGPC was evaluated using a drop weight impact test. The durability properties of GFRGPC were evaluated by subjecting the specimens to freeze-thaw cycles, chloride ion penetration, and sulfate attack.



. Test for Determination of Fineness Modulus Table 1: Sieve Analysis for Fine Aggregate

IS Sieve Size	Weight Retained (gm)	Cumulative Weight Retained (gm)	Cumulative % Weight Retained	Cumulative % Passsing
10mm	0	0	0	100
4.75mm	8	8	1.6	98.4
2.36mm	43	51	10.2	89.8
1.18mm	58	109	21.8	78.2
600micron	87	196	39.2	60.8
300micron	180	376	75.2	24.8
150micron	92	468	93.6	6.4
PAN	31	499	-	0.2
Total	499		241.6	

The Fineness modulus is 2.41. Sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

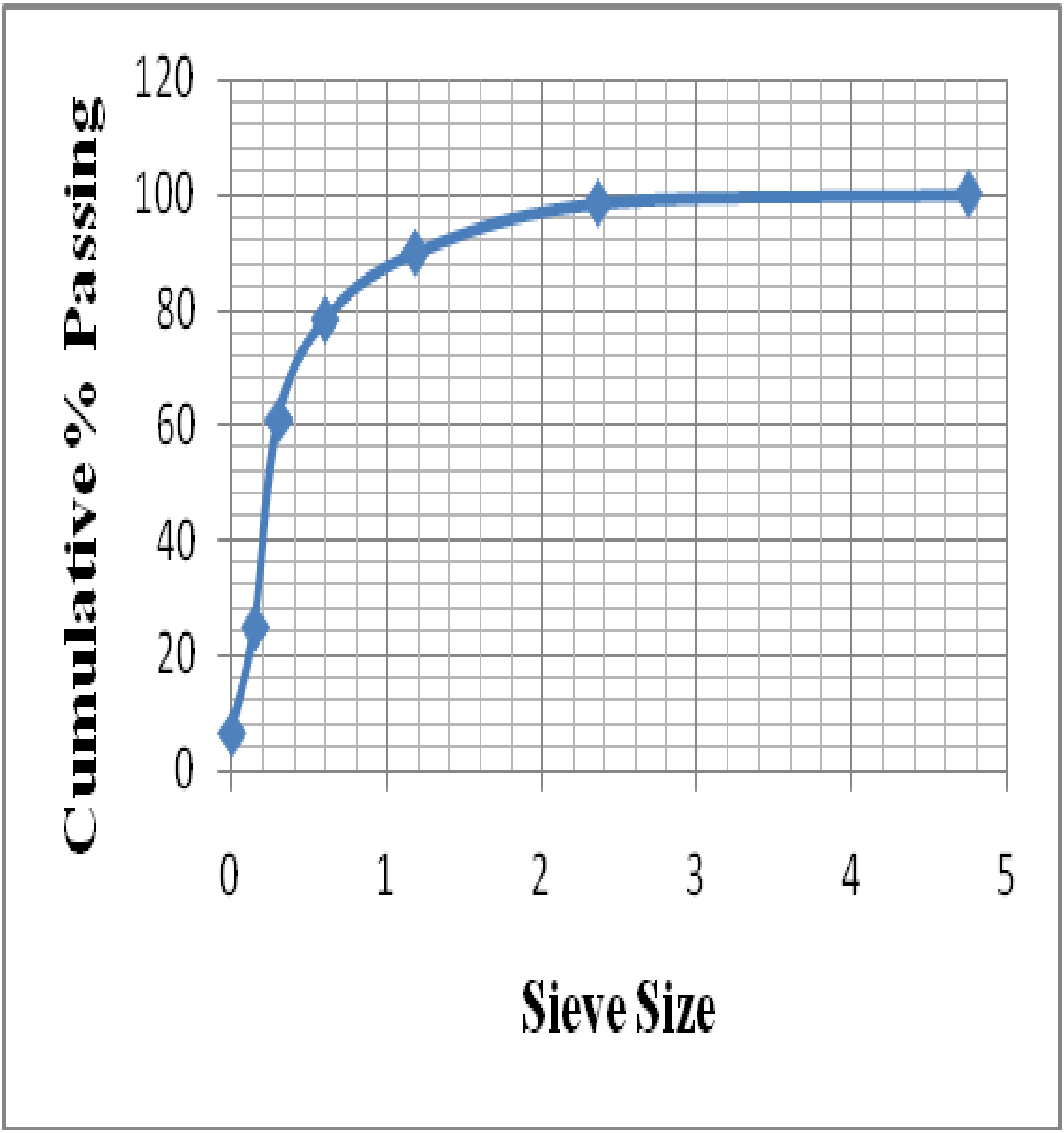
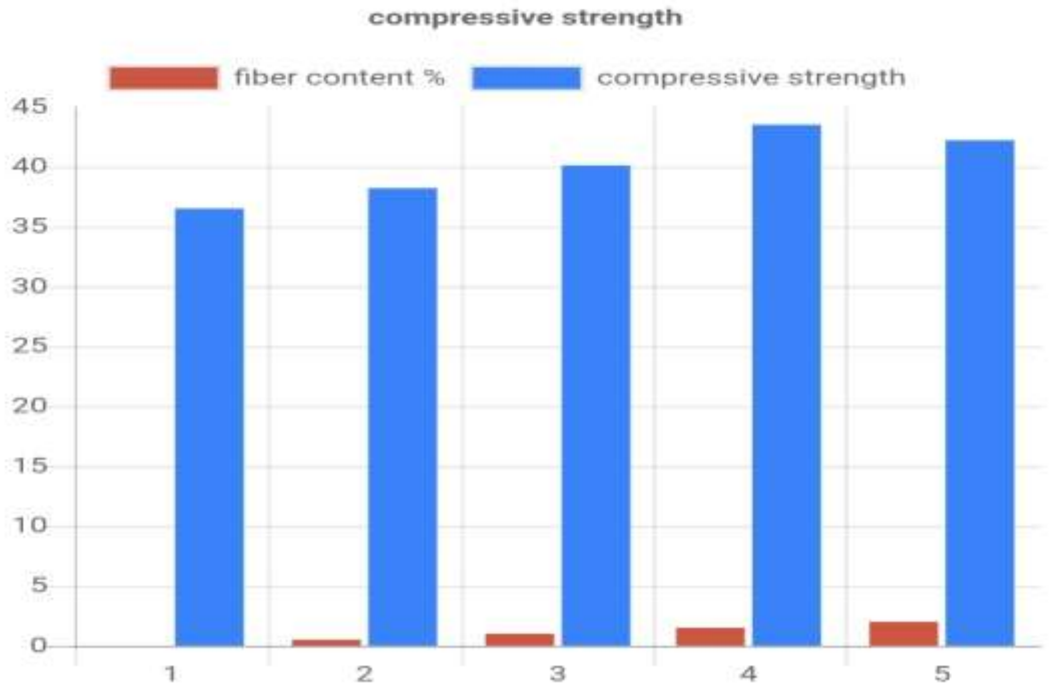

Cumulative % Passing
120
100
80
60
40
20
0
0
1
2
3
4
5
Sieve Size

Table :2 compressive strength

Fiber Content (%)	Compressive Strength (MPa)
0 %	35.6
0.5 %	38.2
1.0 %	40.1
1.5 %	43.5
2.0 %	42.2

This table shows the compressive strength results for GFRGPC at different fiber contents. The compressive strength increased with the increase in fiber content up to 1.5%, beyond which it decreased slightly. The results can be presented in a similar table format for other mechanical properties such as flexural strength and split tensile strength.



Flexural strength results

Table :3

Fiber Length (mm)	Fiber Content (%)	Flexural Strength (MPa)
12	0.5 %	4.8
12	1.0 %	5.3
12	1.5 %	5.9
25	0.5 %	5.1
25	1.0 %	5.7
25	1.5 %	6.5

This table shows the flexural strength results for GFRGPC at different fiber lengths and contents. The flexural strength increased with the increase in fiber content and length, and the optimal fiber length was found to be 25 mm. The results can be presented in a similar table format for other mechanical properties such as compressive strength and split tensile

Split tensile results

Table :4

Fiber Content (%)	Split Tensile Strength (MPa)
0 %	2.5
0.5 %	2.8
1.0 %	3.1
1.5 %	3.4
2.0 %	3.2

This table shows the split tensile strength results for GFRGPC at different fiber contents. The split tensile strength increased with the increase in fiber content up to 1.5%, beyond which it decreased slightly. The results can be presented in a similar table format for other mechanical properties such as compressive strength and flexural strength.

Results and Discussion:

1. The results showed that the addition of glass fibers improved the mechanical properties of GFRGPC.
2. The compressive strength, flexural strength, and split tensile strength increased with the increase in fiber content up to 1.5%.
3. Beyond this value, the mechanical properties decreased due to the clustering of fibers.
4. The flexural strength and toughness of GFRGPC increased with the increase in fiber length, and the optimal fiber length was found to be 25 mm.
5. The impact resistance of GFRGPC increased with the increase in fiber content, and the optimal fiber content was found to be 1.5%.
6. The results also showed that GFRGPC exhibited excellent resistance to chloride ion penetration and sulphate attack, and the addition of glass fibers improved the durability under freeze-thaw cycles.

Conclusion:

The study concludes that the addition of glass fibers improves the mechanical and durability properties of GFRGPC.

- The optimal fiber content was found to be 1.5%, and longer fibers resulted in higher flexural strength and toughness. GFRGPC exhibited excellent resistance to chloride ion penetration and sulfate attack, and the addition of glass fibers improved the durability under freeze-thaw cycles. The study recommends the use of GFRGPC in structural

- The workability of glass fiber geopolymer concrete is medium in range there is no effect of glass fiber on workability of concrete.
- It is found that by partially replacing lime & cement to fly ash in geopolymer concrete eliminate two limitation of geopolymer concrete such as delay in setting time and necessity of heat curing to gain strength.
- On basis of results it is concluded that 0.3% of glass fiber in mix shows optimum results in compression, flexural and split tensile.
- It is observed that adding glass fibersup to 0.3% possible to mix in concrete but in further condition it is difficult to mix glass fibers in homogenously in concrete.
- Compressive, flexural and tensile strength of glass fiber geopolymer concrete is more by replacing lime for ambient curing as compared to replacement to cement
- Glass fiber in geopolymer concrete improve structural strength reduce crack width and control width tightly, thus improved flexural strength and durability of geopolymer concrete

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