© December 2025 | IJIRT | Volume 12 Issue 7 | ISSN: 2349-6002

Strength Evaluation of Fiber Reinforced Geopolymer Concrete

Nayana B S[1], Duragappa M K[2]
[1]*Assistant Professor, Department of Civil Engineering, The Oxford College of Engineering, Bengaluru, Karnataka, India*
[2]*PG student, Department of Civil Engineering, The Oxford College of Engineering, Bengaluru, Karnataka, India*

***Abstract*—Fly ash (FA) and ground granulated blast furnace (GGBS)-based geopolymer concrete (GPC) are growing in popularity as green construction materials. Studies demonstrated that GPC is brittle in nature; however, this drawback could be mitigated by fiber reinforcement. Environmental factors are more easily accessible if locally available sources are used. The purpose of this research is to investigate the impact of fiber integration in GPC. Jute fiber (JF) and coir fiber (CF) were added to the matrix at a rate of 1% total binder. The samples were examined at molarities of 12 and a sodium hydroxide (SH) to sodium silicate (SS) ratio of 2.5. The specimens were molded and allowed to cure in the ambient environment. The results demonstrated that jute fiber reinforcement had a significant impact on the workability, compressive strength, fracture strengths, water absorption, and microstructure parameters of the suggested geopolymer concretes. Increasing the fiber length and volume fractions in the geopolymer matrix reduced slump values and workability while increasing compressive strength. At 28 days, the specimen with a fiber length of 20 millimetres and volume fractions of 0.75% showed the lowest slump value and the highest compressive strength. In addition, specimens with fiber volume fractions of 0, 0.25, 0.5, 0.75, 1, 1.25, and 1.5% shown a significant increase in splitting tensile and flexural strength. Increasing the volume of the jute fibers to% resulted in a slight drop in the strength of the geopolymers. The specimens prepared with a length of 20 mm and a volume of 1% achieved the highest enhancement of splitting tensile strength and compressive strength at 28 days.**

***Index Terms*—Geopolymer Concrete, M Sand, Natural Jute and Coir Fiber, Fly ash, GGBS, Workability, Compressive Strength, Split Tensile Strength, Flexural Strength of beam.**

I. INTRODUCTION

Concrete is the world's most widely used construction material, but its dependence on Ordinary Portland Cement (OPC) creates major environmental problems. Cement manufacturing is highly energy-intensive and releases almost one ton of CO_2 for every ton produced, making it a major source of global emissions. This has increased the need for sustainable alternatives.

Geopolymer Concrete (GPC) is one of the most promising substitutes. Instead of cement, it uses industrial by-products such as fly ash, GGBS, metakaolin, and rice husk ash. When these materials react with alkaline activators like sodium hydroxide and sodium silicate, they undergo geo-polymerization, forming a strong aluminosilicate gel that binds the aggregates. Using GPC provides significant benefits. It can reduce carbon emissions by up to 80–90% and helps utilize industrial waste that would otherwise harm the environment. GPC also offers engineering advantages, including high early strength, excellent chemical resistance, lower shrinkage, and improved durability.

Because of these properties, GPC is becoming popular in power plants, steel industries, precast units, and structures exposed to harsh conditions. In summary, Geopolymer Concrete is a key step toward sustainable construction, offering a low-carbon and high-performance alternative that supports both environmental protection and efficient waste utilization.

II. FIBER REINFORCED CONCRETE (FRC)

FRC is a composite material made by adding discrete, short, and uniformly distributed fibers such as steel, synthetic, glass etc., to cement mortar or concrete to enhance its structural integrity and crack control. It has gained prominence as a material for retrofitting and structural rehabilitation. Addition of fibers will significantly improve the behaviour of concrete in post-cracking by controlling crack propagation, enhancing ductility, impact resistance, and toughness. Unlike plain concrete, which is brittle in nature, FRC provides a composite material with superior energy absorption and durability, making it highly suitable for retrofitting applications.

CARBON FIBER REINFORCED CONCRETE (CFRC):

It is a subset of FRC that uses carbon fibers, offering superior strength-to-weight ratio, stiffness, and corrosion resistance compared to other fibers. CFRC is widely adopted in retrofitting projects due to its ability to greatly increase flexural and shear capacity, especially in critical elements like beams and columns of multi-storey buildings. Application methods include externally bonded carbon fiber sheets or strands, which are designed to enhance seismic resilience and overall performance of the retrofitted structure. Studies show that despite higher costs, CFRC can deliver substantial enhancements in structural stability, making it ideal for demanding retrofitting tasks.

III. OBJECTIVES OF THE STUDY

- Determine the workability of coir and jute fiber reinforced geopolymer concrete.
- To determine the Compression strength of coir and jute fiber reinforced geopolymer concrete by varying % of fibers.
- To determine the Split Tensile Strength of coir and jute fiber reinforced geopolymer concrete by varying % of fibers.
- To determine the Flexural strength of coir and jute fiber reinforced geopolymer concrete beams.

IV. METHODOLOGY

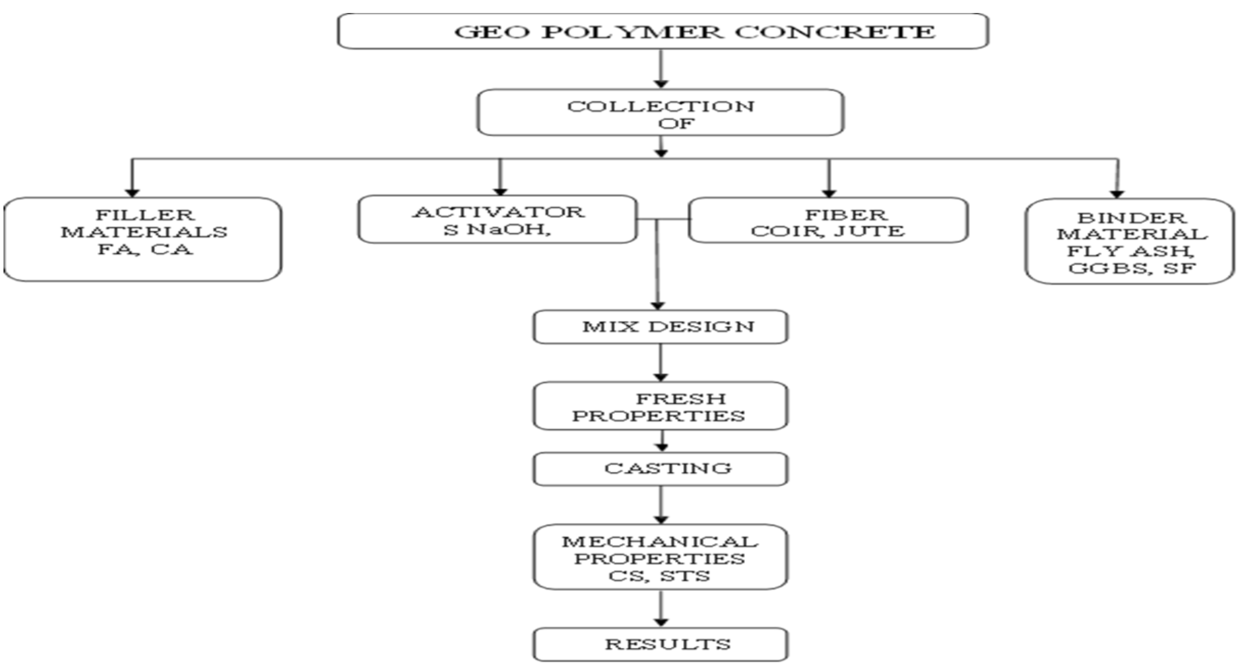

Fig 1: Methodology

➢ PROJECT DETAILS

- Collection and preparation of materials.
- Preparation of alkaline activator solutions.
- Mixing and casting of specimens with varying fiber contents.
- Curing (heat or ambient) based on mix type.
- Testing for compressive, split tensile, and flexural strengths.

- Data analysis and comparison.

➢ MATERIALS USED

- FINE AGGREGATES: - Fine aggregate is a naturally formed material made up of small particles of broken stones, sand, or other mineral components. It typically goes through a 4.75 mm IS sieve and is used in construction to fill pores between coarse aggregates, resulting in improved packing and reduced porosity. Fine aggregate is essential for creating workable, robust, and long-lasting concrete or mortar. Natural sand (river, pit, and sea sand) and artificially manufactured sand (M-sand), which is created by crushing rocks, are usual sources.
- COURESE AGGREGATEL: - Gravel / stone which is the product of natural fragmentation and crushed gravel or stone remain generally known as the Coarse-Aggregate. Coarse-aggregate is stones which stand retained on size 4.75mm sieve as shown in the figure 3.3. Almost all natural aggregates initiate from bed rocks. There are three sorts of rocks: igneous, sedimentary, and metamorphic. In these many characteristics of aggregates depend upon the characteristics of the parent rock itself.
- FLY ASH: - Fly Ash: - Fly ash is a fine, powder particle generated in thermal power stations while they burn pulverized coal. When coal is burned, its mineral impurities (such as clay, quartz, and shale) combine in suspension and are transported away by flue gases. These fused particles evaporate rapidly, which produces tiny spherical particles called fly ash.
- GGBS: - GGBS is a byproduct of the steel manufacturing process. Melting iron ore, limestone, and coke in a blast furnace generates molten iron, and the residual residue, known as slag, cools rapidly with water or steam to form a glassy, granular product. It is then dried and converted into a fine powder process is called Granulated Blast Furnace Slag.
- SILICA FUME: - It is a fine powder that is collected as a byproduct of the manufacturing of silicon metal or ferrosilicon alloys in electric arc furnaces. When silicon is heated to high temperatures, 'silica vapours are emitted. These vapours cool and condense into tiny spherical particles of 'amorphous silica (SiO_2)', which are subsequently caught by pollution control devices. The collected material is called silica fume.
- SODIUM HYDROXIDE: - Sodium hydroxide is an inorganic compound. It is also known as caustic soda with the chemical formula NaOH. It is an ionic compound having sodium cations Na^+ and hydroxide anions OH^-. NaOH is found as a white translucent solid at ambient temperature. In civil engineering chemistry, sodium hydroxide (NaOH), or caustic soda, is primarily used as a powerful alkaline activator in the production of geopolymer concrete and for the chemical stabilization of problematic soils. Due to its strong alkalinity, it reacts with certain materials to create a strong binding matrix.
- SODIUM SILICATE: - In civil engineering chemistry, Na_2SiO_3 (sodium metasilicate) is a form of sodium silicate, also known as water glass. It is a versatile chemical used for various applications, such as a concrete densifier and sealant, a soil stabilizer, and an accelerant for cement. The compound is prized for its ability to increase the strength, durability, and water resistance of construction material.
- COIR FIBER: - Coir fiber is a natural fiber generated from the outer husk of the coconut. It is robust, resilient, and biodegradable, making it an environmentally benign material commonly used in construction, agricultural, and domestic products.

TREATMENT OF COIR FIBER: - Initially cut the fibers into 20mm length and soak the fibers in NaOH solution for 48 hours. After that wash the fibers repeatedly and allow to dry for 24 hours. Resin with (70% of latex+10% of NaOH+20% of water) solution and allow to dip for 15minutes. Later dry for 24hours.

- JUTE FIBER: - Jute fiber is a natural, long, soft, and lustrous vegetable fiber produced from the jute plant's stem and exterior layer (bast). It is typically grown in tropical areas with significant humidity such as India and Bangladesh. Jute is referred to as the "golden fiber" because of its gold-brown appearance and economic significance.

TREATMENT OF JUTE FIBER: - Initially soak fiber in water for 30 minutes and dry, cut the fiber into 20mm length. Prepare 5% of NaOH solution. Immerse the fiber in NaOH solution for 3 hours. Later wash the fiber with water and soak in water for a day. Finally keep the fiber in oven @800C for 6 hours.

- ABIENT CURING: - Ambient curing refers to the process in which concrete, particularly geopolymer concrete, is allowed to harden and develop strength under normal room temperature conditions, typically ranging from 25°C to 35°C. Unlike heat curing, where external heat is applied using ovens or steam chambers, ambient curing relies entirely on natural environmental conditions. This method is especially useful for on-site construction because it does not require any special equipment, making it more practical, economical, and energy-efficient. In geopolymer concrete, ambient curing is possible when reactive materials such as GGBS, fly ash–GGBS blends, or silica fume are used. These materials help accelerate the geo-polymerization process even without elevated temperatures. As a result, the concrete can achieve reasonable strength over time. However, the rate of strength gain is usually slower compared to heat-cured geopolymer concrete. Early-age strength may be lower, but long-term strength can still be satisfactory if the mix design is optimized. Ambient curing is preferred in real-world construction scenarios where heat curing is not feasible. It supports sustainable construction practices by reducing energy consumption and lowering the overall environmental impact. Overall, ambient curing provides a practical balance between performance, cost, and environmental benefits.
- MIX PROPORTION

TABLE 1 MIX PROPORTION

MATERIALS	VOLUME kg/m3
Fine aggregate	754.76 Kg/m3
Coarse aggregate	1132.15 Kg/m3
Alkaline activator liquid	180 Kg/m3
Sodium hydroxide	51.43Kg
Sodium silicate	128.58 Kg
Fly ash (60%)	240 Kg/m3
GGBS (30%)	120 Kg/m3
Silica Fume (10%)	40 Kg/m3
Sodium silicate and sodium hydroxide ratio	2.5
Solution-to-fly ash ratio	0.45

V. ANALYSIS AND RESULTS

- SLUMP CONE TEST

TABLE 2 SLUMP TEST

MIX	SLUMP
GPC0	106
GPC, CF 0.25	94
GPC, CF 0.5	95
GPC, CF 0.75	96
GPC, CF 1	92
GPC, CF 1.25	91
GPC, CF 1.50	86
GPC, JF 0.25	94
GPC, JF 0.5	97
GPC, JF 0.75	92

GPC, JF 1	90
GPC, JF 1.25	94
GPC, JF 1.5	95

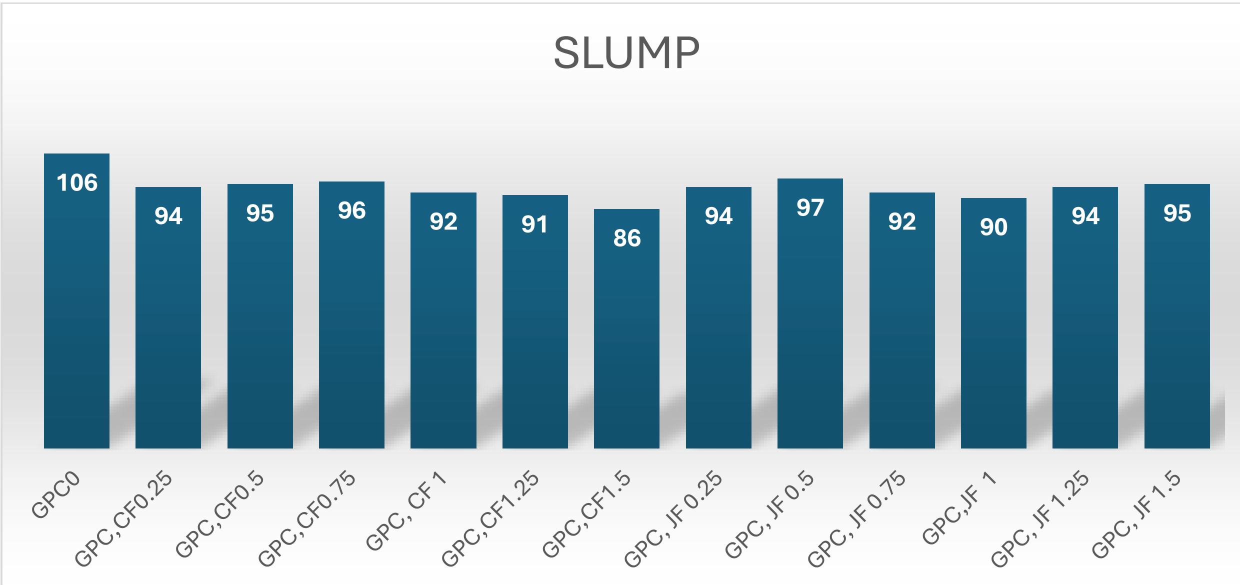

Figure 1 GRAPH SHOWING SLUMP OF GEOPOLYMER CONCRET

Tests were performed for various percentages of coir and jute fiber GPC and values were recorded, the stated range of slump of GPC, CFGPC and JFGPC was 125–75 mm respectively. The workability of GPC is adversely affected by the inclusion of CF and JF. A skeleton is created when fiber distributed haphazardly, which will surely hinder the mixtures' ability to flow. The increase in slump is significantly influenced by the ratio of Na2SiO3/NaOH. Form Fig.22 it is evident that control mix is having better slump flow compared to all other mixes, CF and JF add to the same mix it has reduced by 12.03 % and 8.49 %. Workability is highly dependent on particle form. In the case of GGBS with an angular particle shape, workability is impacted by the higher surface area and high porosity of the silica-based components. The interaction between GGBS and silica leads to the creation of a novel crystalline phase. The alkali fusion of GGBS results in the alteration of some mineral phases into amorphous structures and the creation of new crystalline phases inside the matrix. Specialized equipment or methods, including vibration or self-consolidating concrete formulations, could be required for this. Reduced workability may make it more difficult to remove air gaps during compaction, which might jeopardize the durability and density of the concrete. To get good results, more advanced compaction techniques, including high-frequency vibrators, could be needed.

➢ COMPRESSIVE STRENGTH TEST

TABLE 3 COMPRESSIVE STRENGTH

MIX	7DAYS	14 DAYS	21DAYS
GPC0	22.52	30.2	37.9
GPC, CF 0.25	23.2	31.2	38.2
GPC, CF 0.5	24.54	32.78	39.1
GPC, CF 0.75	24.59	32.96	40.1
GPC, CF 1	25.36	33.3	40.25
GPC, CF 1.25	24.3	33	39.82

GPC, CF 1.50	24.22	32.4	39.5
GPC, JF 0.25	23.6	29.64	37.4
GPC, JF 0.5	23.68	30.62	38.8
GPC, JF 0.75	24.24	31.84	38.98
GPC, JF 1	25.3	32.32	39.6
GPC, JF 1.25	24.26	31.2	39.1
GPC, JF 1.5	23.22	30.4	38.2

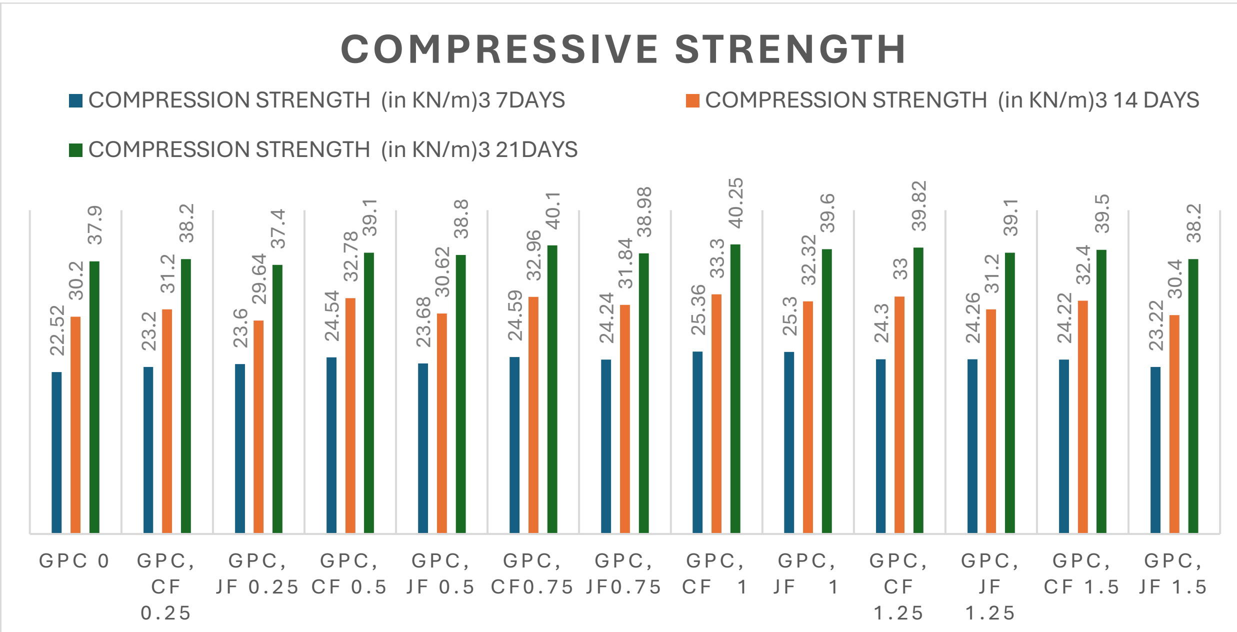

Figure 2 COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE

The graphical illustration of compressive strength for CFGPC and JFGPC at 0%, 0.5%, 1%, 1.5% and 2% fiber content (tested at 7, 14 and 28 days) shows a clear trend in the behaviour of geopolymer concrete reinforced with coir and jute Fibers. For reference, mix GPC1 achieved a compressive strength of 40.25 MPa, while the addition of 1% coir fiber (CF) and 1% jute fiber (JF) resulted in strengths of 39.64 MPa, showing that fibers help control micro-crack propagation and improve load-carrying capacity. The increase in compressive strength up to 1% fiber content is mainly due to the fibers bridging cracks and restricting their propagation. However, beyond 1% fiber dosage, the compressive strength decreases. This reduction occurs because higher fiber volumes reduce the workability and hinder proper compaction, increasing voids inside the matrix.

During the geo-polymerization process, silica and alumina ions dissolve and form aluminosilicate gel (N-A-S-H/C-A-S-H). SEM observations show a dense matrix with fewer voids, supported by the presence of Si, Al, O, and Na key elements derived from fly ash, GGBS and silica fume through polycondensation. With 1% coir fiber, the microstructure becomes denser and less porous compared to control GPC, resulting in improved compressive strength. However, increasing fiber content beyond this level leads to poor packing, higher porosity, and reduced strength because the mixture becomes too viscous and difficult to compact. A similar trend is observed with jute fiber. The addition of jute up to 1% increases compressive strength, but further addition reduces strength due to loss of fluidity and difficulty in compaction. Research findings support this behaviour, indicating that fibers enhance compressive and tensile strength only up to an optimum percentage. Excessive fiber length or volume reduces flowability and negatively affects the concrete's hardened properties. Fibers help resist lateral expansion under compression, but when the dosage exceeds the optimal level, the lack of workability results in strength reduction

➢ SPLIT TENSILE STRENGTH TEST

TABLE 3 SPLIT TENSILE STRENGTH TEST

MIX	7DAYS	14 DAYS	21DAYS
GPC0	2.52	3.38	4.2
GPC, CF 0.25	2.63	3.52	4.28
GPC, CF 0.5	2.75	3.66	4.34
GPC, CF 0.75	2.82	3.72	4.38
GPC, CF 1	2.84	3.78	4.48
GPC, CF 1.25	2.8	3.7	4.42
GPC, CF 1.50	2.7	3.62	4.36
GPC, JF 0.25	2.6	3.4	4.28
GPC, JF 0.5	2.64	3.42	4.32
GPC, JF 0.75	2.68	3.52	4.38
GPC, JF 1	2.79	3.6	4.42
GPC, JF 1.25	2.72	3.51	4.31
GPC, JF 1.5	2.58	3.38	4.24

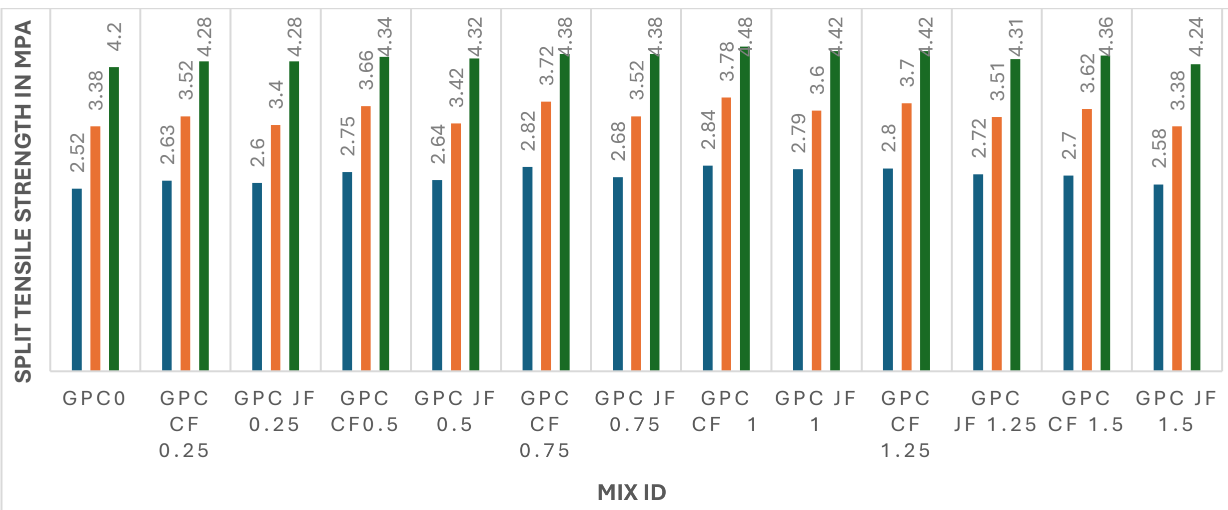

Figure 3 GRAPH SHOWING SPLIT TENSILE STRENGTH OF GPC

Split tensile strength test was performed on the moulds of size 150X300mm. shows that 7 days split tensile strength varies from 2.5 to 2.6Mpa, 14 days split tensile strength varies from 3.35 to 3.5Mpa, and 28 days split tensile strength varies from 4.21 to 4.38Mpa. The highest split tensile strength obtained is for mix GPC1, which is 2.41Mpa for 7days, 3.7Mpa for 14 days and 4.47 for 28 days. This variation in split strength is due to the coconut fiber content provided in the mix. The increase in voids and low density of coconut fiber are the reason for the drop in split tensile strength, which was previously caused by the ductile nature of the fiber. The source material used was rich in silica, alumina, and calcium oxide, which helped in the development of alumino silicate hydrates and C-A-S-H gel—resulting in high strength properties of geopolymer concrete. Better-compacted geopolymer concrete was produced by filling the pores created by the inclusion of coconut fibers with C-S-H gel. Geopolymer concrete has a better bonding with fibers, which resulted in a gain in strength due to the addition of coconut fibers. Figure 24 depicts the Split tensile strength of concrete with variable proportions of JF. It can be noted that Split tensile strength of concrete is enhanced with jute fibers up to 1% addition and then decreased with further addition of jute fibers due to lack of fluidity in a similar manner to the CS.

- FLEXURAL STRENGTH TEST

TABLE 4 FLEXURAL STRENGTH VALUE

Specimen	Deflection (mm)	Frist crack load (kN)	Ultimate deflection (mm)	Ultimate Load (kN)
0.25%	4.1	21.2	14.05	34.5
0.5%	4.4	24.2	14.21	40.3
1%	6.1	28.21	16.18	43.5
1.25%	6.1	30.65	17.9	48

The test results show how different fiber contents affect the flexural behavior of the specimens. As the percentage of fibers increases from 0.25% to 1.25%, both the first crack load and the ultimate load show a consistent improvement. This indicates that fibers play an important role in delaying crack initiation and enhancing the overall load-carrying capacity of the material. The increase in first crack load means the fibers help the matrix resist early cracking more effectively. The ultimate deflection also increases with higher fiber content. This shows that the material becomes more ductile and can undergo larger deformations before failure. Higher ductility is a desirable property because it allows

the structure to absorb more energy and avoid sudden failure. Even though the deflection at first crack shows only slight variations, the overall trend suggests that fibers improve the flexibility of the mix. Specimens with 1% and 1.25% fibers demonstrate noticeably higher deflection and improved post-cracking behavior.

Overall, the results clearly show that increasing fiber content enhances strength, crack resistance, and ductility. The highest performance is observed at 1.25% fiber content, where both load capacity and deformation capability reach their maximum values.

VI. CONCLUSIONS

- Fiber-reinforced geopolymer concrete exhibits superior strength and toughness.
- Sustainable construction material with reduced carbon footprint.
- After the 28th day of curing, the geopolymer concrete made with 1% coir fiber reaches its maximum average compressive strength.
- After the 28th day of curing, the geopolymer concrete made with 1% jute fiber reaches its maximum average compressive strength.
- The geopolymer concrete made with 1% coir fiber and 1% jute fiber reaches its maximum average split tensile strength.

REFERENCE

[1] HM, A. K, & Shoba M. S. January 2025. Durability and microstructure of fiber-reinforced geopolymer concrete with FA and GGBS. In structure (Vol.71. p.108096). Elsevier.

[2] Pole Tanovic, B., Kopecks, K., & Marta, I. (2024). Fiber horrification improves the long-term properties f hemp fiber-reinforcement fly ash-based geopolymer mortar. Construction and building Materials, 446

[3] Raza, A., Salmi, A., El Ouni, M.H., Shabbir, F., Ghazouani, N., Ahmed, B., & Hendy, A.S. (2024). A comprehensive review on martial characterization and thermal properties of geopolymers: potential of various fibers. Case studies in construction materials, 21

[4] Shahedan, N. F., Hadibarata, T., Abdullah, M.M.A.B., Jusoh, M. N.M., Abd Rahim, S. Z., Isia, I., &Juwono, F. H. (2024). Potential of fly ash geopolymer concrete as repairing and retrofitting solution for marine infrastructure: A review case studies in construction materials,20

[5] Mohammed, A.D. A. A., Ronghui, W., & Husein, G.F (2024). Mechanical Properties of Natrural jute Fiber-reinforced Geopolymer concrete:

Effects of various lengths and volume Fractions. Journal of composites science, 8 (11).
[6] Veerappan, P., Mani, I., John, A., & Madhavan, H. (2024). Experimental studies of coir and jute-fiber reinforced concrete with M-sand. Materia (Rio de Janeiro),29
[7] Raza, A., Salmi, A., El Ouni, M.H., Shabbir, F., Ghazouani, N., Ahmed, B., & Hendy, A.S. (2024). A comprehensive review on material characteristics and thermal properties of geopolymers: potential of various fibers. Case studies in construction materials, 21
[8] Abdalla, J.A., hawileh, R. A., Bahurudeen A. Jyothsan, G., Sofi, A., Shanmugam, V., & Thomas, B.S. (2023). A comprehensive review on the use of natural fiber in cement/ geopolymer concrete: A step towards sustainability case studies in construction materials,19
[9] Ozturk M., Sengun, K., & Arslan, G. (2023, February). CFRP contribution to load carrying capacity of retrofitted geopolymer concrete beams. In structure (Vol. 48, pp. 1391-1402). Elsevier.
[10] Asaduzzaman, S.M., & Islam,G.S(2023). Using jute fiber to improve fresh and hardened properties of concrete. Journal of natural fibers ,20(2)
[11] Rajendran, M., Bakthavatvhalam, K., & Leela Bharathi, S. M (2023). Review on the hybridized application of natural fiber in the development of geopolymer concrete. Journal of natural fibers,20(1)
[12] Abdalla J. A, Hawileh. R. A, Bahurudeen A, Jyothsna G, Sofi, A, Shanmugam V, and Thomas B. S (2023).
[13] Sudha C, Sambasivan A K, PR. K. R. and Jegan M. (2022). Investigation on the performance of reinforced concrete columns jacketed by conventional concrete and geopolymer concrete. Engineering Science and Technology, and International Journal, 36
[14] Karmegam Aarthi, Siva Avudaiappam, Mughed Amaran, Pablo Guindos, Nikolai Ivanovich Vatin, and Roman Fediuk. “Retrofitting RC Beams using high-early strength alkali-activated concrete.” Case Studies in construction Material 17 (2022)
[15] Ahmad, J. Arbili, M. M, Majdi, A, Althoey, F, Farouk Deifalla, A, & Rahmawati, C. (2022). Performance of concrete reinforced with jute fiber (natural fiber); A review Journal of Engineered Fiber and Fabrics 17
[16] Li, W, Shumuye, E. D, Shiying . T, Wang. Z, & Zerfu, K. (2022). Eco-friendly fiber reinforced geopolymer concrete: A critical review on the micro structure and long-term durability properties. Case studies in construction Materials,16
[17] Salman, W. D, & Mansor, A. A, (2021). Fibrous geopolymer paste composite for near surface mounted strengthening of reinforced concrete beams in flexura. Case studies in construction Materials.