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# Performance Evaluation Of Coir Fibre In Enhancing Strength Of Fly Ash-Based Geopolymer Concrete

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With its reduced carbon footprint, better durability, and efficient use of industrial by-products like fly ash, geopolymer concrete (GPC) has become a viable substitute for OPC-based concrete in terms of sustainability. Despite these benefits, geopolymer concrete isn't always suitable for structural uses due to its brittleness and poor tensile strength. To get around these issues, the material's mechanical performance may be improved by adding natural fibers like coir fiber. Coir fiber is an excellent reinforcing material since it is renewable, plentiful, and made from the husks of coconuts. It has high tensile strength, is flexible, and does not degrade in alkaline conditions. This research delves into the examination of coir fiber's efficacy in strengthening geopolymer concrete based on fly ash in three ways: compressive, split tensile, and flexural. The ideal dose for strength augmentation was determined by using different percentages of coir fiber. Incorporating coir fibers into the geopolymer matrix greatly enhances its ductility, toughness, and fracture resistance, according to the results. In order to encourage environmentally friendly methods in the construction industry, the research highlights the double advantage of sustainable building and efficient waste management. Therefore, coir-reinforced GPC is an exciting new development for longer-lasting and environmentally friendly infrastructure.

**Keywords:** Geopolymer concrete, Fly ash, Coir fiber, Mechanical strength, Sustainable construction.

## I. INTRODUCTION

Because of its heavy use on OPC, the building sector is among the top industries in the world when it comes to carbon emissions. Because it uses a lot of energy and produces almost a ton of carbon dioxide for every ton of cement, making OPC is a major contributor to global warming. The hunt for eco-friendly substitutes in building supplies has been driven by this critical environmental concern. An attractive and environmentally preferable alternative to OPC-based concrete is geopolymer concrete (GPC), which has recently attracted a lot of interest. Developed by alkali activating industrial by-products like fly ash, GPC offers a solution to waste materials that would be difficult to dispose of and minimizes carbon emissions. One of the most common starting materials for making geopolymer binders is fly ash, which is a waste product of thermal power plants that burn coal. Geopolymerization is a perfect fit for its high silica and alumina content. An impressive chemical resistance, low permeability, and high compressive strength are all characteristics of the geopolymer concrete

made from fly ash. However, geopolymer concrete's brittleness and lower tensile and flexural strengths when contrasted with regular concrete are significant drawbacks. Its ductility and fracture resistance are crucial in structural applications, but these drawbacks prevent it from being widely used.
Incorporating fibers into the geopolymer matrix has been investigated as a potential solution to these restrictions. Fibers enhance concrete's ductility, toughness, and post-cracking behavior by acting as crack-arresting agents. Natural fibers, which are abundant, inexpensive, and environmentally friendly, have attracted more and more attention among the many explored fiber types, including basalt, glass, polypropylene, and steel. Coconut husk fiber, or coir fiber, is an example of a potentially useful reinforcing material. Coir fiber is plentiful in tropical nations like the Philippines, Sri Lanka, and India due to the abundance of coconuts grown there. It is a lignocellulosic fiber that is resistant to saltwater degradation, has a high tensile strength, and is robust. When mixed with cementitious or geopolymer matrices, coir fiber's exceptional resilience in alkaline settings makes it a great choice over other natural fibers such as jute or sisal. Also, coir fiber is renewable and biodegradable, so it's a great sustainable option that fits in with the worldwide trend toward eco-friendly building. By acting as a bridge between fractures and a stress transfer agent, coir fiber improves the mechanical characteristics of geopolymer concrete. The tensile and flexural strengths are enhanced because the fibers provide more resistance to the propagation of cracks. Better bonding with the geopolymer matrix is achieved by the fiber's rough surface roughness, which in turn improves load-bearing capacity and facilitates stress transmission. In addition, structural parts exposed to dynamic or impact stresses greatly benefit from the increased toughness shown by coir-reinforced GPC.

Coir fiber reinforcing also helps with sustainable waste management, which is a major plus. A lot of people throw away the coconut husks, which are used to make coir, since they are considered agricultural waste. Their use in building materials not only makes better use of agricultural waste but also lessens the environmental damage that comes from dumping them in the wrong places. Therefore, coir-reinforced geopolymer concrete tackles two important issues at once: the need for sustainable building practices and the proper exploitation of agricultural waste. Adding coir fiber to GPC in carefully measured amounts may greatly enhance its mechanical qualities, according to many experimental investigations. Fiber dosage, aspect ratio, and mix dispersion are the primary determinants of reinforcing efficacy. The homogeneity of the matrix may be negatively impacted by problems like poor workability and fiber clumping, which can result from an excessive amount of fiber content. So, to get the most out of it, you really need to figure out what proportion of coir fiber is best.

Coir fiber's usage in GPC not only improves mechanical performance, but also has positive effects on society and the economy. Rural towns in poor nations often have an abundance of coir fiber, which means that incorporating it into the building industry might open up new avenues for livelihood for those living there. All three of these goals—reducing reliance on synthetic fibers, increasing resource efficiency, and supporting socioeconomic development—are in line with the concepts of a circular economy. Examining how well coir fiber improves the strength characteristics of geopolymer concrete based on fly ash is the main objective of this research. The study's overarching goal is to identify the ideal dose of reinforcement that optimizes compressive, split tensile, and flexural strength by methodically examining the effect of various coir fiber percentages. We anticipate that the results will shed light on how to better create environmentally friendly, long-lasting concrete products for use in building structures. As a result, coir-reinforced geopolymer concrete stands out as a game-changing method that combines cutting-edge materials with environmental concerns. It is a giant leap toward greener infrastructure as it uses natural fibers to increase strength while also decreasing the environmental implications of cement manufacture.

## II. LITERATURE REVIEW

Afriansya, Rahmad et al., (2023) Instead of using Portland cement as a binder, geopolymers use a material that has reacted with an alkaline activator, such NaOH or Na2SiO3, and has a high SiO2 and Al2O3 concentration. In addition, since concrete and mortar are so prone to cracking, polypropylene fiber (PPF) is an absolute must. Coal fly ash (FA) was used as a precursor in this investigation, which examined the effects of introducing PPF at concentrations ranging from 0% to 1%. A range of 0.25%, 0.50%, 0.75%, and 1% were used for the testing. In order to maintain a steady flow, this study additionally used a superplasticizer (SP) and extra water (EW). The tests investigated the microstructure, workability, and strengths of geopolymer mortar. The workability results were in the 140–220 mm range. The compressive strength of the geopolymer mortar was raised to 73.3 MPa and the flexural strength to 9.92 MPa with the addition of 0.5% PPF. In addition, the microstructure of the geopolymer was studied using energy dispersive X-ray studies and electron microscopy scans.

Ayeni, Olugbenga et al., (2022) this study explored the use of coir fibers obtained from coconut husks to develop geopolymer composites with improved properties that are based on metakaolin. The husks of coconuts are an agro-waste product that adds to pollution and other environmental problems. To create the samples, we mixed metakaolin powder with varying percentages of coir fiber weight:0.5,1.0,1.5, and 2.0 percent. The investigation used an alkaline solution with a 10 M NaOH concentration and a Na2SiO3 to NaOH mass ratio of 0.24. The materials were tested for compressive and flexural strengths, bulk density, and ultrasonic pulse velocity (UPV) after 28 days of curing. Imaging microscopy, scanning electron microscopy, and Fourier transform infrared spectroscopy (FTIR) were used for further examination of the microstructure of the materials. The compressive strength reached 21.25 $N/mm^2$ at 0.5% and the flexural strength reached 10.39 $N/mm^2$ at 1%, respectively, and this study showed that fiber content had no influence on these values. The results showed that the bulk density of the geopolymer samples dropped from 2113 $kg/m^3$ to 2045 $kg/m^3$ when the coir fiber content rose. The geopolymer samples showed velocities between 2315 and 2717 m/s. Composite materials made from metakaolin-based geopolymers and 0.5-1.0% coir fiber have improved mechanical properties and are more sustainable in the long run.

Kumar, Amit & Sharma, Pushpendra. (2022) Twenty percent crushed rock dust (CRD) and zero percent fly ash (FA) were used as cement substitutes in this investigation. In addition, the researchers progressively increased the fly ash content while lowering the CRD concentration, and they added 0.5% coir fiber by weight to the cement. The ultimate ratio that was employed was 10% CRD to 10% fly ash. By incorporating this ingredient into concrete, not only is the material's strength enhanced, but its correct disposal also reduces its environmental impact.

This research looked at the concrete's compressive and flexural strengths when ordinary Portland cement was replaced with CRD, fly ash, and 0.5% coirfiber. Compared to eleven various concrete mixes, one that contains 0 percent CRD, fly ash, and fiber is considered nominal. When compared to the nominal mix, combinations including CRD, fly ash, and fiber exhibit greater strength increases in compressive and flexural testing. Cement combined with 12.5% CRD, 7.5% fly ash, and 0.5% coir fiber was determined to be the strongest composition. The property workability of different concrete mixes was also examined. Coir fiber makes concrete a little easier to work with than CRD and fly ash-prepared concrete. The ductility and crack-prevention properties of freshly mixed concrete are enhanced by the addition of fibers.

Gannavaram, Venkat Praveen & Kurre, Pandu. (2020) many building types have had to settle with marginal soils—poor quality soils—because optimal granular soils are not readily available in many construction sites. Since the development of reinforcing soil, a variety of materials, including geosynthetics, have been used as reinforcement. Beyond its use in geosynthetics, coir fiber has several technical uses, including reinforcing soils that are too fragile to support construction. Coir fiber is randomly mixed into the soil mixture with the aim of strengthening it. Fly ash has been used on several building projects due to its accessibility as a waste resource. The effort is running at a loss since preserving and maintaining natural resources is more costly than making appropriate use of fly ash. Of the many techniques for altering soil, cement modification stands out among chemical stabilization, lime stabilization, and others. In order to make marginal soil non-plastic, this study investigates the idea of treating it with 3% cement. A locally available cement-modified marginal soil was reinforcing tested with coir fiber and fly ash. The main objective of this study is to find out if adding randomly distributed coir fiber as reinforcement to cement-modified marginal soil that already includes fly ash improves its shear strength and other strength metrics. A series of laboratory studies, including direct shear and unconfined compressive strength tests, were carried out on marginal soil. This combination of 10% fly ash, 2% coir, and other reinforcements had a shear strength that was 1.5 to 2 times greater than that of regular marginal soil. Thus, reinforced soil structure development might make use of marginal soil, as the experimental examination provides a technique for estimating the enhancement of its shear strength.

Zulfiati, Ria et al., (2020) One way to reduce carbon emissions in the atmosphere is to use environmentally friendly concrete. Industrial waste items including fly ash, coal ash, palm husk ash, and rice husk ash are mixed into eco-concrete, making it a more sustainable alternative to cement. One recently produced cement substitute, fly ash, is already widely used, especially in geopolymer concrete. In this study, natural fibers like coconut fiber are used. Coconut fiber is an additional natural fiber alternative for composites made from geopolymers. This research examined the compressive and flexural strengths of mortar with different coconut fiber lengths (10 mm, 20 mm, and 30 mm) and fiber percentages (0, 0.25%, and 0.50% by weight of the mortar). Pavers made solely of geopolymerized fly ash. The NaOH solutions utilized were 14 M and 16 M. Researchers discovered that mortar with 30 mm fiber length and 0.50% fiber percentage in a 16 M NaOH solution had a compressive strength of 40.016 MPa after 28 days of age, and a maximum flexural strength of 8.799 MPa.

NarasimhaSwamy, P.A.N.V.L. et al., (2017) the behavior of coir fiber's durability is evaluated in fly ash-based geopolymer concrete. Coir fiber must be treated with a rubber latex solution before to being used in geopolymer concrete. From 0% to 3%, 0.75%, 1.5%, and 2.25% are all possible percentages when using a 25 mm Coir fiber. A solution of sodium silicate and sodium hydroxide was used throughout the geopolymerization procedure. A binding agent to fly ash ratio of 0.45 is used. 10M and 12M molarities are used. To avoid tiny fissures, reinforcing coir fiber is used. Consequently, this might be helpful when resistance to microcracks is an important need.

## III. RESEARCH METHOD

The PT Jaya Beton Indonesia lab follows all procedures according to the SNI, or Indonesian National Standards. With 0%,0.25%,0.5%, and 1% coconut fiber, the intended compressive strength value of the concrete specimens is f'c = 35 MPa. The concrete cylindrical test item utilized in this study is 10 cm in diameter and 20 cm in height. The physical qualities of all materials, including both fine and coarse aggregate, are tested in compliance with the Indonesian National Standards (SNI). Regarding the methods for choosing mixes for regular concrete, SNI-03-2834-2000 is referenced in the production of test items in this study. The tensile splitting test and the compressive strength test for concrete are both governed by SNI 1974-2011 and SNI 03-2491-2002, respectively.

The properties of fibrous concrete are greatly affected by the L/D ratio, which is the ratio of the length to diameter of the fibers. The length-to-diameter ratio (L/D) was calculated as 50 by cutting coconut fiber to a length of 15 mm and a diameter of 0.3 mm for this investigation. Reinforcing concrete using coconut fibers at a length-to-diameter ratio of 50:100 is ideal. With this ratio, the fibers may penetrate the concrete cavity thoroughly, making it far more resistant to cracks. Equation is used to determine the amount of fiber weight needed per cylindrical mold.

$$\text{Weight} = p \times \text{vol of mold} \times \rho \qquad (1)$$

Where:

p = Percentage of coconut fibre (%)

vol. of mold = $1/4 \times \pi \times 0{,}12 \times 0{,}2$ (m3)

$\rho$ = fibre Density (= 1.150 kg/m3)

Figure 1 depicts the study project's flowchart, and Table 1 details the amount of fiber weight required for each 10-by-20-centimeter cylindrical mold.

**Table 1: Fibre weight per cylindrical mold**

| Specimen code | % Fibre | Fibre Volume (m3) | Fibre weight (gram) |
|---|---|---|---|
| BGPSK0 | 0 | | |
| BGPSK 0.25 | 0,25 | 3,93.10-6 | 4,51 |
| BGPSK 0.5 | 0,5 | 7,85.10-6 | 9,03 |
| BGPSK 1 | 1,0 | 15,70.10-6 | 18,06 |

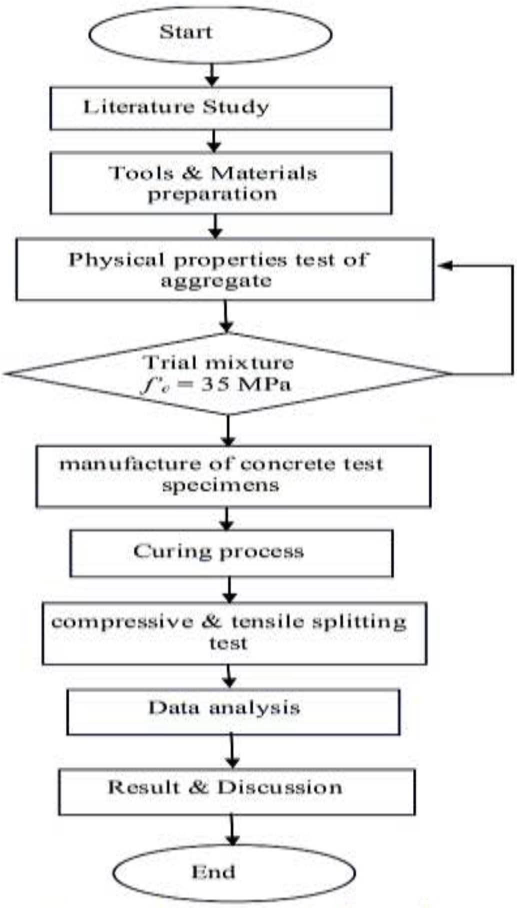


**Figure 1: Research flowchart**

Fine and coarse aggregate physical parameters are shown in Table 2, whereas the mixture composition of geopolymer concrete per cubic meter is shown in Table 3.

**Table 2: Physical properties of aggregate**

| Type of test | Coarse Agg. | Fine Agg. |
|---|---|---|
| Specific Gravity | 2.54 | 2.52 |
| Unit Weight | 1.44 | 1.44 |
| Materials finer than 0.075 mm | 0.80 | 3.75 |
| Absorption | 2.86 | 2.89 |
| Abration | 20.67 | - |
| Fineness Modulus | 7.78 | 3.23 |

**Table 3: Geopolymer Concrete Mixture Per 1m3**

| Material | Weight | Units |
|---|---|---|
| Coarse Aggregate | 1074,17 | kg |
| Fine Aggregate | 776,21 | kg |
| Fly ash | 386,71 | kg |
| NaOH | 48,34 | kg |
| Na2SiO3 | 145,02 | Kg |
| Water | 36,01 | Liter |

## IV. RESULT AND DISCUSSION

This study determined the specific gravity, compressive strength, and tensile splitting strength of geopolymer concrete using a battery of experiments.

### Unit Weight

Weighing the concrete is the initial step in testing its compressive strength. The intended application of the concrete's weight is determined by this weighing. Figure 1 shows the specific gravity growth data for each composition of coconut fiber derived from the results of the weight test.

**Table 4: Unit weight of geopolymer concrete with coconut fibre**

| Mix ID | 7 Days (kg/m³) | 14 Days (kg/m³) | 28 Days (kg/m³) |
|---|---|---|---|
| BGSK 0 | 1888.0 | 1998.5 | 2112.0 |
| BGSK 0.25 | 1987.0 | 2104.0 | 2223.5 |
| BGSK 0.5 | 2082.0 | 2194.5 | 2324.0 |
| BGSK 1 | 2185.0 | 2222.0 | 2310.0 |

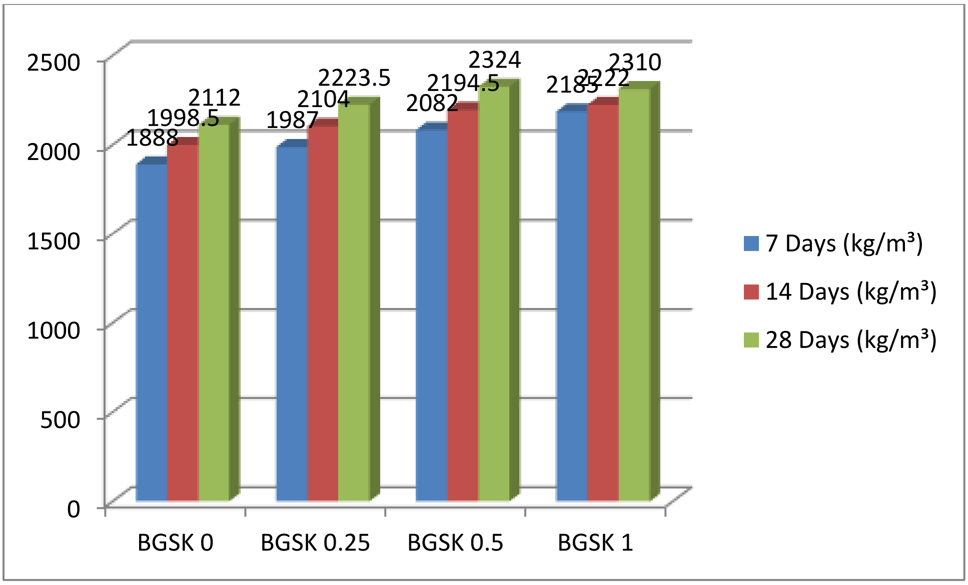


**Figure 2: Unit weight of geopolymer concrete with coconut fibre**

The data in Table 4 illustrates the variation in unit weight of geopolymer concrete with the incorporation of coconut (coir) fibre over different curing periods. It is observed that the unit weight increases consistently with both the addition of fibre and the curing age. For the control mix (BGSK 0), the unit weight rises from 1888.0 kg/m³ at 7 days to 2112.0 kg/m³ at 28 days, indicating the densification of the geopolymer matrix as the hydration and geopolymerization reactions progress. With increasing fibre content, the unit weight further increases; for example, BGSK 1 shows an increase from 2185.0 kg/m³ at 7 days to 2310.0 kg/m³ at 28 days. This trend suggests that the inclusion of coir fibre contributes to a denser composite, likely due to improved packing and interfacial bonding between the fibre and the geopolymer matrix. The results also indicate that curing duration significantly affects the unit weight, reflecting the ongoing reaction of fly ash, alkaline activator, and aggregates, leading to a more compact structure. However, it is important to note that excessively high fibre content may slightly disrupt the matrix homogeneity, which could influence workability and overall density. Overall, the observed increase in unit weight with fibre addition and curing age highlights the positive role of coir fibre in enhancing the structural compactness of geopolymer concrete.

**Compressive Strength Test**

The data presented in Table 5 highlights the effect of coconut (coir) fibre incorporation on the compressive strength of geopolymer concrete at 7, 14, and 28 days. The control mix (BGSK 0) shows a steady increase in compressive strength from 13.85 MPa at 7 days to 20.35 MPa at 28 days, reflecting the progressive geopolymerization and matrix densification over time. The addition of coir fibre generally enhances the compressive strength, with BGSK 0.5 exhibiting the highest values—19.80 MPa at 7 days, 26.50 MPa at 14 days, and 29.50 MPa at 28 days—indicating that an optimal fibre content can improve the load-bearing capacity by reinforcing the matrix and controlling micro-crack propagation. Interestingly, a higher fibre content in BGSK 1 slightly reduces the 7-day strength compared to BGSK 0.5 but still shows significant improvement at later ages (24.70 MPa at 14 days and 26.50 MPa at 28 days), suggesting that excessive fibre may initially interfere with workability or compaction, though it contributes positively as the matrix matures. Overall, the results demonstrate that incorporating moderate amounts of coir fibre in geopolymer concrete can enhance its compressive strength, particularly at 14 and 28 days, by improving internal bonding and crack resistance while maintaining structural integrity over time

Coconut fiber acts as a space filler and a structural reinforcer in concrete, which increases the material's compressive strength. The addition of coconut fiber to concrete may boost its density and strength by filling any gaps that may exist. Additionally, coconut fiber may boost concrete's compressive strength by improving the bond between cement and aggregate. This study's findings corroborate those of other studies showing that adding coconut fiber to concrete increases its compressive strength. For instance, studies have shown that geopolymer concrete may have a compressive strength 10% higher with the inclusion of 0.5% coconut fiber. Additionally, studies have shown that geopolymer concrete may have its compressive strength increased by 12% with the inclusion of 0.5% coconut fiber.

**Table 5: Compressive strength of geopolymer concrete with coconut fibre 7, 14 and 28 days**

| Mix ID | 7 Days (MPa) | 14 Days (MPa) | 28 Days (MPa) |
|---|---|---|---|
| BGSK 0 | 13.85 | 16.90 | 20.35 |
| BGSK 0.25 | 15.75 | 19.20 | 23.10 |
| BGSK 0.5 | 19.80 | 26.50 | 29.50 |

| | | | |
|---|---|---|---|
| BGSK 1 | 15.25 | 24.70 | 26.50 |

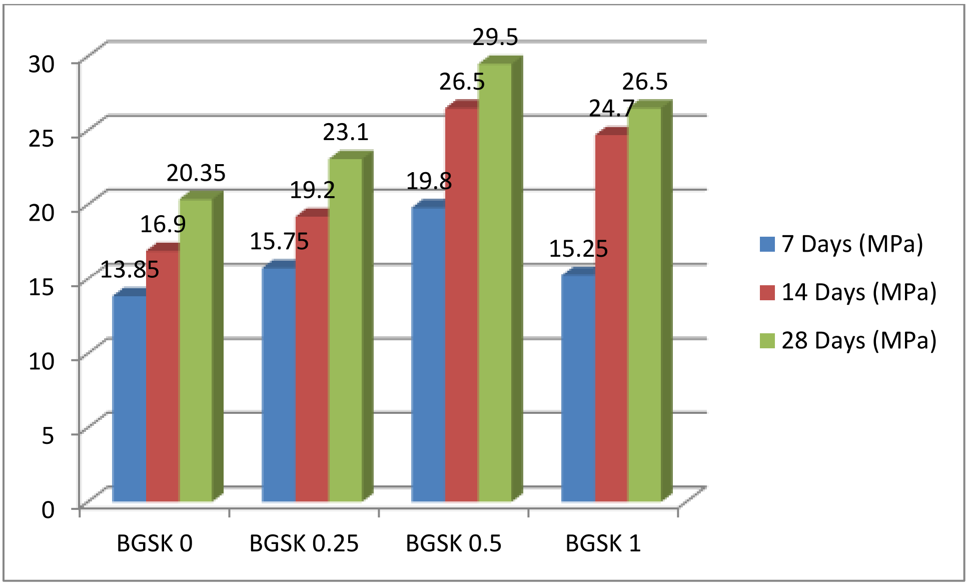


**Figure 3: Compressive strength of geopolymer concrete with coconut fibre 7, 14 and 28 days**

The geopolymer concrete, which was created from fly ash and coconut fiber, did not reach the desired compressive strength, however. It was discovered that coconut fiber might be a game-changer in the green concrete industry. Coconut fiber may improve mechanical properties thanks to its one-of-a-kind qualities. By incorporating coconut fiber into concrete, we can make better use of coconut waste and produce greener building materials, which may lead to exciting new possibilities for sustainable development. Despite the lack of compressive strength, green concrete built from coconut fiber is possible.

### Concrete Tensile Strength Test

The enormous compressive stress that concrete can endure is one of its key characteristics. In most cases, tensile stress is too much for concrete to handle because of its brittle nature. In most cases, concrete's tensile strength is only about 9–15% of its compressive strength.

To determine how well geopolymer concrete reinforced with fiber could resist tensile loads, scientists conducted a tensile test on the material. The concrete sample is subjected to a tensile force until fractures form as part of this testing procedure. The concrete was tested at7,14, and 28 days of age. The findings of the tests reveal that the tensile strength of geopolymer concrete that has been reinforced with fiber increases as the concrete ages. Increasing the proportion of coconut fiber in geopolymer concrete resulted in an improvement in its tensile strength (Figure 2).

**Table 6: Tensile strength of geopolymer concrete with coconut fibre 7, 14 and 28 days**

| Mix ID | 7 Days (MPa) | 14 Days (MPa) | 28 Days (MPa) |
|---|---|---|---|
| BGSK 0 | 0.72 | 1.98 | 2.30 |
| BGSK 0.25 | 0.85 | 2.35 | 2.70 |
| BGSK 0.5 | 0.87 | 2.78 | 2.92 |
| BGSK 1 | 1.10 | 2.35 | 2.85 |

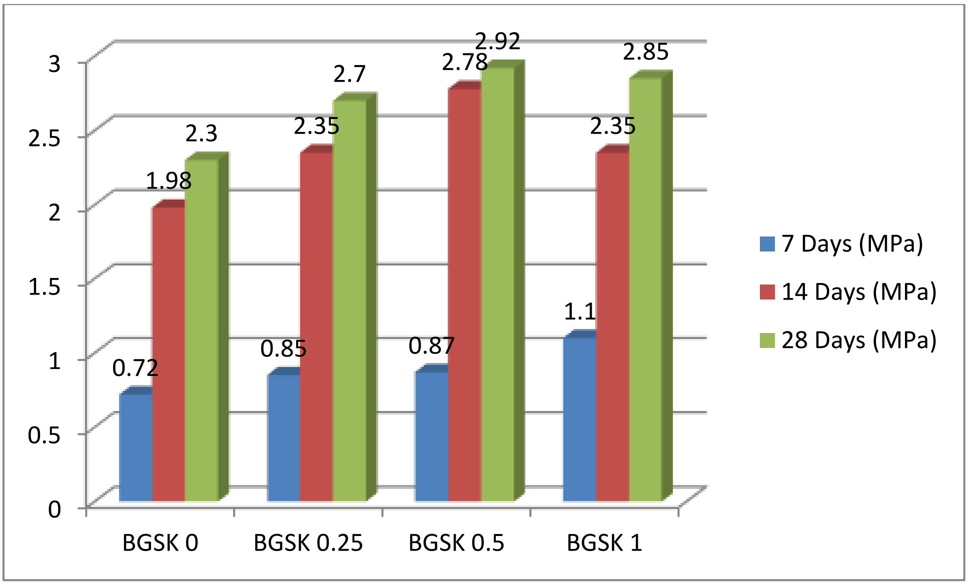


**Figure 4: Tensile strength of geopolymer concrete with coconut fibre 7, 14 and 28 days**

The data in Table 6 presents the tensile strength of geopolymer concrete reinforced with coconut (coir) fibre over curing periods of 7, 14, and 28 days. The control mix (BGSK 0) exhibits a steady increase in tensile strength from 0.72 MPa at 7 days to 2.30 MPa at 28 days, reflecting the progressive development of the geopolymer matrix and improved cohesion of the composite. The inclusion of coir fibre enhances tensile performance, with BGSK 0.5 showing the highest overall tensile strength—0.87 MPa at 7 days, 2.78 MPa at 14 days, and 2.92 MPa at 28 days—indicating that an optimal fibre content can effectively bridge micro-cracks and improve stress transfer within the matrix. BGSK 1 demonstrates a slightly higher early-age strength (1.10 MPa at 7 days) but shows comparable 28-day strength (2.85 MPa) to

BGSK 0.5, suggesting that excessive fibre content may improve early crack resistance but does not significantly enhance long-term tensile capacity. Overall, the results indicate that moderate incorporation of coconut fibre can significantly improve the tensile strength of geopolymer concrete, enhancing its resistance to cracking and increasing its durability, especially at later curing stages.

This study's findings corroborate those of other studies that investigated how incorporating coconut fiber into geopolymer concrete affected its tensile strength. The results of studies are one of them. According to this study, geopolymer concrete may have its tensile strength increased by 13% with the inclusion of 0.5% coconut fiber. Additional studies have shown that geopolymer concrete may have its tensile strength increased by 12% with the inclusion of 0.5% coconut fiber.

## V. CONCLUSION

Geopolymer concrete offers an environmentally sustainable alternative to conventional cement-based concrete by utilizing fly ash and alkali activators to form a durable binder. However, its brittle nature and low tensile strength limit its structural performance. This study highlights the role of coir fiber as an effective reinforcement for overcoming these shortcomings. The addition of coir fiber significantly enhances the mechanical properties of fly ash-based geopolymer concrete by improving compressive, tensile, and flexural strengths. The fiber's ability to bridge microcracks and provide additional toughness ensures improved ductility and crack resistance. Beyond mechanical improvements, the use of coir fiber contributes to sustainability by utilizing an abundantly available agricultural by-product. This not only minimizes waste disposal issues but also supports rural economies through value-added applications of coir. The findings reaffirm that coir-reinforced geopolymer concrete integrates environmental, social, and economic benefits, making it an ideal material for future construction practices. With further optimization in fiber dosage and mix design, coir-reinforced GPC holds great potential for widespread adoption in infrastructure projects requiring durable, eco-friendly, and resilient construction materials.

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