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Original Article

Effect of Rice Husk Ash on the Properties and Performance of Geopolymer Concrete

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Abstract - *This study examines the influence of Rice Husk Ash (RHA) as an additional substance in geopolymer concrete (GPC), specifically analyzing its impact on workability, setting times, compressive strength, and splitting tensile strength. The experimental findings demonstrate that an increase in RHA concentration results in a decrease in workability and a speeding up of setting times while yielding significant enhancements in both compressive and tensile strengths. More precisely, the compressive strength experiences an increase from 16 MPa to 35 MPa, while the splitting tensile strength rises from 1.3 MPa to 2.6 MPa as the amount of RHA increases. The changes are caused by the large surface area and water absorption qualities of RHA, which affect the consistency and curing characteristics of the mixture. Although there have been significant improvements in the mechanical qualities, the reduced workability and shorter setting periods pose issues that require more investigation. The study highlights the potential of RHA as an environmentally friendly addition, providing a sustainable option to traditional materials and aiding in reducing building waste. Suggestions for future research encompass enhancing the RHA composition to achieve a harmonious blend of mechanical performance and workability, examining the long-term durability and environmental resistance, establishing standardized production procedures, exploring other industrial by-products, and conducting thorough assessments of the life cycle and economic aspects. By focusing on these specific areas, the development of RHA-enhanced GPC will be promoted, facilitating its incorporation into sustainable building methods and improving its overall effectiveness and environmental footprint.*

Keywords - *Geopolymer Concrete, Rice Husk Ash, Compressive Strength, Split Tensile Test, Setting Value.*

1. Introduction

There are various problems associated with concrete. A lot of research shows various methods to improve the performance of concrete. Geopolymer concrete is a great alternative with various applications, as shown in Figure 1, for some concrete with good strength and durability. Geopolymer Concrete (GPC) differs from traditional Portland cement concrete in both composition and formation. There are some research gaps in the basic literature investigations for the performance evaluation of geopolymer concrete using rice husk ash. Unlike conventional concrete, which relies on cement hydration to form calcium-silicate-hydrate (C-S-H) gel, GPC uses geopolymerization which is a sophisticated technique that transforms various alumino-silicate minerals as shown in Figure 2 which is materials containing anionic Si-O-Al linkages into useful substances known as inorganic polymers or geopolymers., a chemical reaction between alumino-silicate minerals and alkaline activators [1, 2].

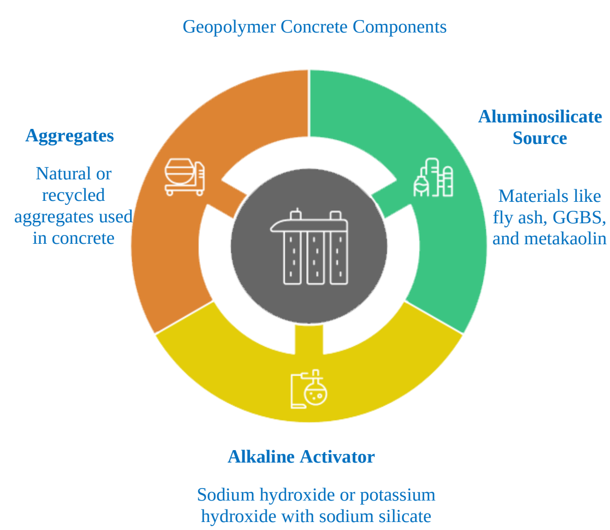

Fig. 1 Primary composition of geopolymer concrete

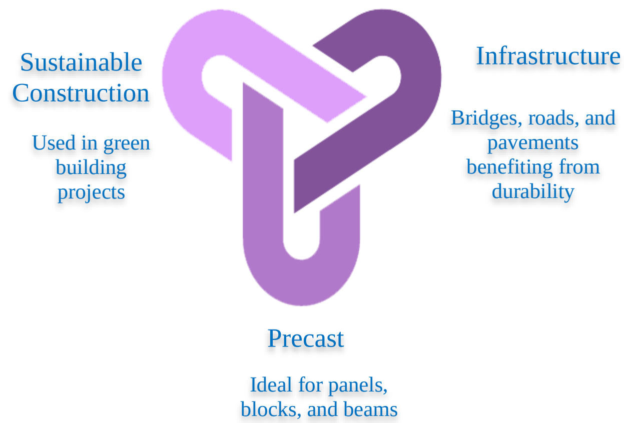

Fig. 2 Application of geopolymer concrete

This process produces alumino-silicate gels with a robust network structure, enhancing GPC's durability, chemical resistance, and mechanical properties [3, 4].GPC's main components are alumino-silicate minerals (e.g., fly ash, GGBFS, metakaolin, and RHA) that supply silicon and aluminum for geopolymer networks [5, 6]. Alkaline activators like sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) initiate and drive the geopolymerization reaction [7]. The resulting GPC exhibits superior mechanical strength, thermal stability, and chemical resistance, making it a viable alternative to traditional concrete, especially in demanding conditions [8].

Table 1 compares GPC's features, including its manufacturing process and environmental benefits.

Table 1. Characteristics and composition of geopolymer concrete

Aspect	Material	Process	Components	References
Type	Geopolymer Concrete	Geopolymerization	Alumino-Silicate Materials, Alkaline Activators	[1], [2], [3], [4]
Binder Formation	Geopolymer Gels	Alumino-Silicate Reaction	Silicon (Si), Aluminum (Al)	[3], [4], [5]
Comparison	Vs. Portland Cement	No Cement Hydration	Fly Ash, GGBFS, Metakaolin, RHA	[1], [2], [5], [6]
Activators	Sodium Hydroxide	Initiates Geopolymerization	Sodium Silicate	[7]
Applications	Harsh Environments	Chemical Exposure	High Reactive Silica & Alumina	[8], [4], [6]
Environmental Impact	Sustainability	Alternative to Cement	Three-Dimensional Alumino-Silicate Frameworks	[4], [6], [7]
Suitable for	Aggressive Chemicals	Cement-Free Construction	Dissolution of Alumino-Silicate Materials	[7], [8]
Key Outcome	Improved Durability	Non-Hydraulic Binder	Gels Form Structural Framework	[3], [6], [8]
Overall Benefit	Enhanced Properties	C-S-H Gel Alternative	Alkaline Environment	[8], [7], [6]

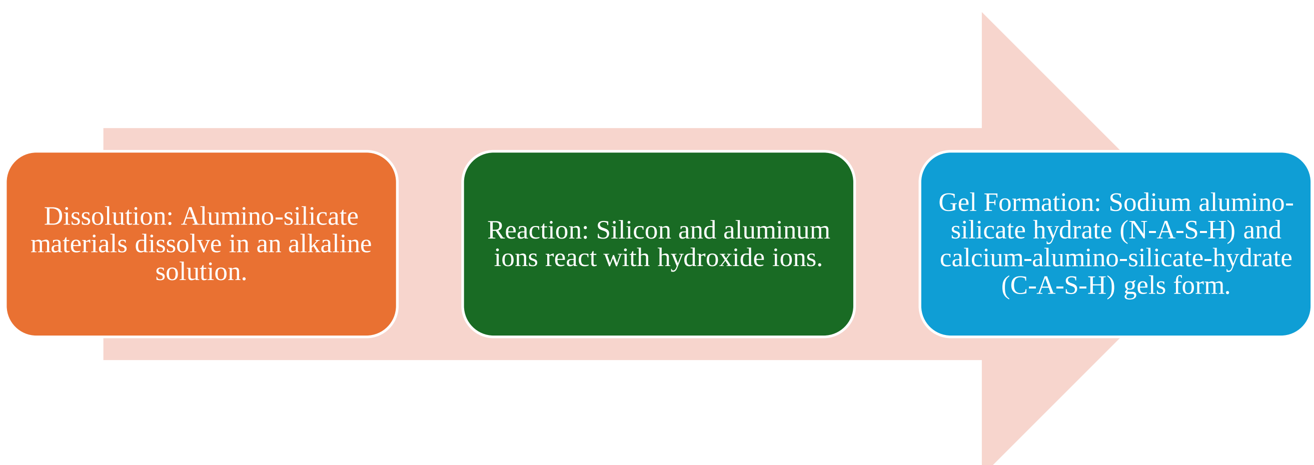

Fig. 3 The geopolymerization processes

1.1. Chemical Reactions and Mechanisms

The geopolymerization process involves key chemical reactions between Alumino-silicate minerals and alkaline activators [9]. When combined with an alkaline solution, Alumino-silicate materials release silicon and Aluminum ions, which then react with alkaline hydroxide ions to form Alumino-silicate gels. The main reaction can be expressed as:

$$SiO_2+Ca(OH)_2+H_2O \rightarrow C\text{-}S\text{-}H \text{ gel} \quad (1)$$

The reaction of Alumino-silicate materials with sodium hydroxide (NaOH) produces sodium Alumino-silicate hydrate (N-A-S-H) gel, which is crucial for the geopolymer matrix's durability and structural integrity. Additionally, combining calcium-containing materials like GGBFS with Alumino-silicate materials generates Calcium-Alumino-Silicate-Hydrate (C-A-S-H) gels [10]. Figure 3 illustrates the geopolymerization process, including the dissolution of Alumino-silicate materials in an alkaline solution and the formation of N-A-S-H and C-A-S-H gels.

1.2. Properties of Geopolymer Concrete

Geopolymer Concrete (GPC) provides comparable or superior compressive and tensile strength compared to traditional concrete [11]. It exhibits excellent durability, highly resistant to chemicals, fire, and extreme temperatures [12]. Environmentally, GPC lowers CO_2 emissions by reducing reliance on Portland cement and requires less energy for production [13]. Table 2 outlines GPC's key attributes, including strength, durability, fire resistance, and environmental benefits, and Figure 4 shows the properties.

Fig. 4 Properties of geopolymer concrete

Table 2. Properties of geopolymer concrete

Aspect	Property	Description	References
Compressive Strength	Comparable or higher	Matches or exceeds traditional concrete strength	[11]
Tensile Strength	Generally higher	Stronger due to dense, well-bonded microstructure	[11]
Durability	Superior	Resists chemicals, high temperatures, and degradation	[12]
Fire Resistance	Better	Improved fire resistance and thermal stability	[12]
Environmental Benefits	Reduced CO_2 and energy	Lowers emissions, recycles waste, uses less energy	[13]

2. Rice Husk Ash (RHA): Characteristics and Applications

2.1. Production and Properties

Rice Husk Ash (RHA) is a by-product of rice milling, formed by burning rice husks at temperatures between 600°C and 800°C [14]. This process converts organic material into ash, which is then cooled, treated, and often ground into a fine powder to improve its effectiveness as a cementitious additive.RHA primarily consists of silica (SiO_2), making up 70% to 90% of its weight, which is crucial for its pozzolanic activity. It also contains smaller amounts of alumina (Al_2O_3), iron oxide (Fe_2O_3), and calcium oxide (CaO), along with other trace elements. RHA's physical properties include small particle size, large surface area, and a porous structure, enhancing its reactivity and effectiveness in concrete [15].

The pozzolanic activity of RHA involves its reaction with Calcium Hydroxide (CH) from Portland cement hydration. This reaction produces calcium-silicate-hydrate (C-S-H) gel, improving the concrete's strength and durability [16].

2.2. Benefits of Using RHA in Concrete

Integrating Rice Husk Ash (RHA) into concrete enhances strength and sustainability. RHA increases compressive and tensile strengths by forming additional C-S-H gel, boosting compressive strength by up to 20% [17, 18]. Environmentally, RHA reduces the need for Portland cement, lowering CO_2 emissions and recycling agricultural waste [19]. This supports circular economy principles by converting waste into valuable resources. Table 3 outlines RHA's production methods, properties, and benefits, emphasizing its impact on concrete performance and sustainability [20].

2.3. Incorporation of RHA in Geopolymer Concrete

Rice Husk Ash (RHA) significantly affects the workability of Geopolymer Concrete (GPC), typically reducing slump and making the mix less fluid due to RHA's fine particles and high water absorption [21].

This impact is more pronounced than with additives like Silica Fume (SF) and Fly Ash (FA) due to RHA's larger surface area. Ensuring a balanced RHA concentration is crucial for maintaining workability while optimizing its pozzolanic benefits. Adjustments to the water-to-binder ratio or the use of superplasticizers can help counteract reduced workability.

Figure 5 illustrates the RHA production process, its chemical composition, and its advantages in concrete, such as enhanced strength and sustainability.

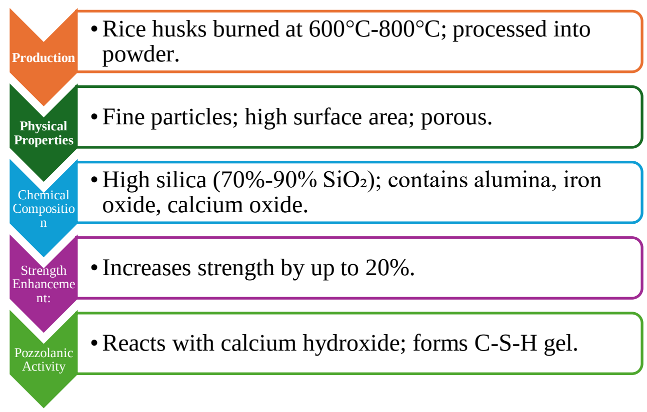

Fig. 5 Characteristics and Applications of Rice Husk Ash (RHA)

Table 3. Characteristics and Applications of Rice Husk Ash (RHA)

Aspect Production & Properties	Description	Details	References
Production	Rice husks burned at 600°C-800°C	Ash cooled, processed, and ground into powder	[14]
Chemical Composition	High silica (70%-90% SiO_2)	Contains alumina, iron oxide, calcium oxide	[15]
Physical Properties	Fine, high surface area	Porous particles enhance reactivity	[15]
Pozzolanic Activity			
Mechanism	Reacts with calcium hydroxide	Forms C-S-H gel, boosts strength	[16]
Benefits in Concrete			
Strength Enhancement	Up to 20% stronger	Improves compressive and tensile strength	[17], [18]
Environmental Benefits	Reduces CO_2 emissions	Recycles waste, lowers carbon footprint	[19]
Sustainability	Circular economy support	Converts waste into valuable resources	[20]

The impact of Rice Husk Ash (RHA) on Geopolymer Concrete (GPC) is critical for its application across various uses[22]. RHA accelerates the setting times due to its pozzolanic activity, which enhances geopolymerization. For example, GPC with increased RHA content significantly reduces initial and final setting times compared to mixes without RHA, benefiting projects requiring rapid strength development [23, 24]. However, this rapid setting may complicate placement and finishing processes. RHA also improves the mechanical properties of GPC, including compressive and tensile strengths. Studies show that RHA can increase compressive strength up to 35 MPa, compared to 16 MPa in control mixes without RHA, due to the formation of additional geopolymer gels [26, 27].

Similarly, tensile strength is enhanced, with RHA-blended mixes reaching up to 2.6 MPa, compared to 1.3 MPa in control mixes, attributed to improved microstructure and reduced porosity [28]. Including RHA enhances GPC's durability, making it more resistant to chemical attacks and freeze-thaw cycles. RHA's pozzolanic reactions densify the concrete's microstructure, increasing resistance to sulfates, acids, and freeze-thaw conditions, essential for structures exposed to harsh environments [30, 31]. Over time, RHA's contribution to GPC enhances the material's longevity, making it more suitable for challenging applications [32].

2.4. Research Findings and Analysis from the Literature

Numerous studies have explored the impact of incorporating Rice Husk Ash (RHA) into Geopolymer Concrete (GPC). Research indicates that RHA significantly influences GPC's mechanical properties, workability, and durability. A study by [35] found that increasing RHA content from 0% to 30% led to a 120% improvement in compressive strength compared to the control mix, attributed to enhanced pozzolanic activity. Another study by [36] observed a decrease in workability with higher RHA levels, suggesting the use of superplasticizers or water-to-binder ratio adjustments to maintain workability. Additionally, [37] reported that RHA improved GPC's resistance to chemical attacks and freeze-thaw cycles, enhancing its long-term durability under harsh conditions.

2.5. Knowledge Gaps and Future Research Directions

Additional study is needed to fill in certain important gaps in our understanding of Geopolymer Concrete (GPC) combined with Rice Husk Ash (RHA). Examining how RHA-blended GPC holds up over time in different kinds of environments is one important field. The material's long-term stability, resistance to deterioration, and durability are unknown due to a paucity of longitudinal studies, even if short-term studies have shed light on the immediate advantages. Optimizing mix designs is also necessary for finding the optimal ratios of RHA and other components that enhance performance without sacrificing workability. Improving RHA's usefulness in GPC might be as simple as creating application-specific prediction models.

3. Methodology

3.1. Materials and Properties

The study used sand and coarse aggregates (10 mm and 20 mm) with specific properties carefully measured to ensure mix consistency. The specific gravities were 2.54 for sand, 2.65 for the 10 mm coarse aggregate, and 2.72 for the 20 mm coarse aggregate. Water absorption values were 0.80% for sand, 0.89% for the 10 mm coarse aggregate, and 0.35% for the 20 mm coarse aggregate. Sand also had a silt content of 3.92% and bulking of 13.64%. Alkaline activators included sodium hydroxide (NaOH) with 99.42% purity, dissolved to create a 14M solution, and sodium silicate (Na_2SiO_3) with a composition of 30.35% SiO_2 and 14.45% Na_2O.

3.2. Mix Design and Preparation

The mix design aimed to evaluate the impact of replacing fly ash with silica fume and rice husk ash on geopolymer concrete properties. Consistent mix proportions were maintained, varying the silica fume-to-fly ash and rice husk ash-to-fly ash ratios while keeping the sodium hydroxide concentration at 14M. Proportions included 400 kg/m³ of fly ash and varied amounts of rice husk ash, with 600 kg/m³ of sand and specified quantities of coarse aggregates and superplasticizers. The preparation involved dry mixing of the materials for two minutes, followed by adding alkaline solutions and superplasticizers for an additional three minutes.

Table 4. Mix proportions

Mix Name	RHA/FA Ratio	L/B Ratio	SS/SH Ratio	FA (kg/m³)	RHA (kg/m³)	SH (kg/m³)	SS (kg/m³)	SPs (kg/m³)	Sand (kg/m³)	CA 10 mm (kg/m³)	CA 20 mm (kg/m³)
GPRHA0	0/100	0.45	2	400	0	60	120	2	600	400	800
GPRHA1	10/90	0.45	2	360	40	60	120	2	600	400	800
GPRHA2	20/80	0.45	2	320	80	60	120	2	600	400	800
GPRHA3	30/70	0.45	2	280	120	60	120	2	600	400	800

Table 4 details the mix proportions for four geopolymer concrete formulations: GPRHA0, GPRHA1, GPRHA2, and GPRHA3. Each mix varies in the ratio of Rice Husk Ash (RHA) to Fly Ash (FA), with GPRHA0 having no RHA, GPRHA1 at 10% RHA, GPRHA2 at 20% RHA, and GPRHA3 at 30% RHA. The liquid-to-binder (L/B) ratio is consistent at 0.45, and the sodium silicate to sodium hydroxide (SS/SH) ratio is maintained at 2 for all mixes. The binder content decreases from 400 kg/m³ to 280 kg/m³ of FA as RHA increases from 0 kg/m³ to 120 kg/m³. Sodium hydroxide and sodium silicate are kept constant at 60 kg/m³ and 120 kg/m³, respectively, with superplasticizers added at 2 kg/m³. Sand and coarse aggregates are consistently used at 600 kg/m³, 400 kg/m³, and 800 kg/m³ for all mixes, respectively.

3.3. Specimen Preparation and Curing

The mixed geopolymer concrete was cast into molds of various sizes for different tests: 100 mm cubes for compressive strength, 100 x 200 mm cylinders for splitting tensile strength, and 100 x 100 x 500 mm prisms for flexural strength. Molds were filled in layers and compacted to remove air pockets. The specimens were initially cured in a controlled environment at 23 ± 2°C and 70% ± 5% relative humidity for 24 hours. After demolding, they were further cured at 20°C and 90% relative humidity until testing to ensure optimal mechanical properties and result consistency.

3.4. Discussion of Results

The workability, setting times, compressive strength, and splitting tensile strength of Geopolymer Concrete (GPC) with Rice Husk Ash (RHA) added as an additive were among the important qualities examined in the study.

Figure 6 presents the percentage composition of various chemical components found in fly ash, significantly impacting its use in concrete production. Silicon dioxide (SiO_2) is the predominant component, constituting 51.2% of the fly ash. Its high concentration is crucial for providing the pozzolanic properties necessary for enhancing concrete's strength and durability. Aluminum oxide (Al_2O_3), making up 29.1% of the fly ash, also contributes to these pozzolanic activities, improving the mechanical properties of concrete. Iron (III) oxide (Fe_2O_3) accounts for 9.2% and affects the color and magnetic properties of the fly ash, as well as its overall chemical reactivity. Calcium oxide (CaO), present at 2.24%, is essential for the cementitious properties of the fly ash; it reacts with water to form calcium hydroxide, which then interacts with other components to create cementitious compounds. Magnesium oxide (MgO), at 1.43%, influences concrete's time and expansion properties, requiring careful management to avoid performance issues. Sodium oxide (Na_2O) and potassium oxide (K_2O) are present at 0.78% and 2.38%, respectively; both can contribute to the alkali-silica reaction, leading to expansion and cracking if not properly controlled. Sulfur trioxide (SO_3), comprising 0.26%, affects the setting time and strength development of concrete, with high levels potentially causing expansive reactions that may result in cracking. Finally, the loss on ignition (LOI) is 3.41%, indicating the amount of unburned carbon and other volatile materials in the fly ash, which can impact concrete's workability and air entrainment. Understanding these components is vital for optimizing fly ash use in concrete mixtures and ensuring its performance in construction applications.

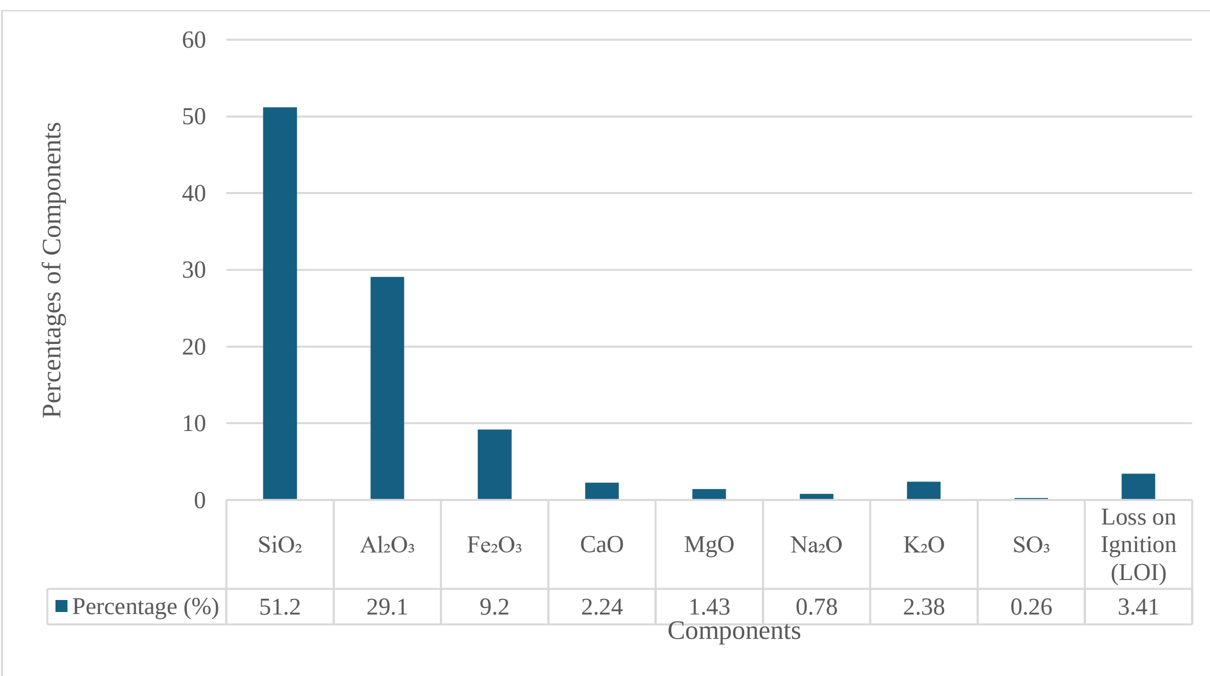

Fig. 6 Chemical composition of Fly Ash

Table 5. Properties of aggregates

Property	Sand	Coarse Aggregate 10 mm	Coarse Aggregate 20 mm
Specific Gravity	2.54	2.65	2.72
Water Absorption	0.80%	0.89%	0.35%
Silt Content (Sand)	3.92%	-	-
Bulking (Sand)	13.64%		

Table 5 provides detailed properties of the aggregates used in the study. It includes measurements for sand and coarse aggregates of 10 mm and 20 mm sizes. The specific gravities are 2.54 for sand, 2.65 for 10 mm coarse aggregate, and 2.72 for 20 mm coarse aggregate. Water absorption values are 0.80% for sand, 0.89% for the 10 mm c c cage aggregate, and 0.35% for the 20 mm coarse aggregate. Sand has a silt content of 3.92% and a bulking factor of 13.64%, with no corresponding values provided for the coarse aggregates. This table summarizes the essential properties that affect the performance and consistency of the concrete mix.

Table 6. Slump values for geopolymer concrete with rice husk ash

Mix Name	RHA/FA Ratio	Slump (mm)
GPRHA0	0/100	125
GPRHA1	10/90	110
GPRHA2	20/80	95
GPRHA3	30/70	80

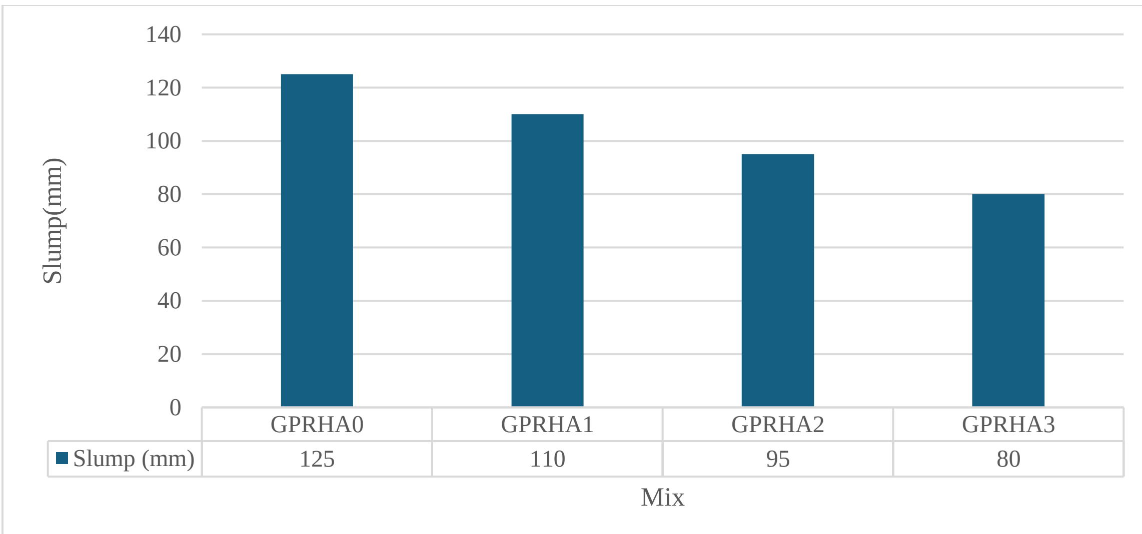

Fig. 7 Slump Values for Geopolymer Concrete with Rice Husk Ash

Table 6 presents the slump values for geopolymer concrete mixes that incorporate varying rice husk ash (RHA) ratios to Fly Ash (FA). The slump test measures concrete's workability, with higher slump values indicating a more fluid mix. In the mix GPRHA0, which contains no RHA (0/100 RHA/FA ratio), the slump value is the highest at 125 mm, reflecting the most workable or fluid concrete. As the RHA content increases in subsequent mixes, there is a noticeable decrease in slump values, indicating reduced workability.

For GPRHA1, where 10% of the fly ash is replaced with rice husk ash (10/90 RHA/FA ratio), the slump value decreases to 110 mm, suggesting a slight reduction in fluidity. In GPRHA2, with a 20% RHA content (20/80 RHA/FA ratio), the slump value drops further to 95 mm, showing a continued decrease in workability. The trend reaches its lowest point with GPRHA3, which has the highest RHA content at 30% (30/70 RHA/FA ratio), resulting in a slump value of 80 mm, indicating the stiffest and least workable concrete mix.

Figure 7 visually represents these findings, showing a clear inverse relationship between RHA content and the slump values of geopolymer concrete. As the proportion of rice husk ash increases, the workability of the concrete decreases, leading to a stiffer mix. This trend highlights the impact of increasing RHA content on the fresh properties of geopolymer concrete, which can have practical implications for concrete handling and placement during construction.

Table 7. Setting times for geopolymer concrete with rice husk ash

Mix Name	RHA/FA Ratio	Initial Setting Time (min)	Final Setting Time (min)
GPRHA0	0/100	260	490
GPRHA1	10/90	220	440
GPRHA2	20/80	190	400
GPRHA3	30/70	160	360

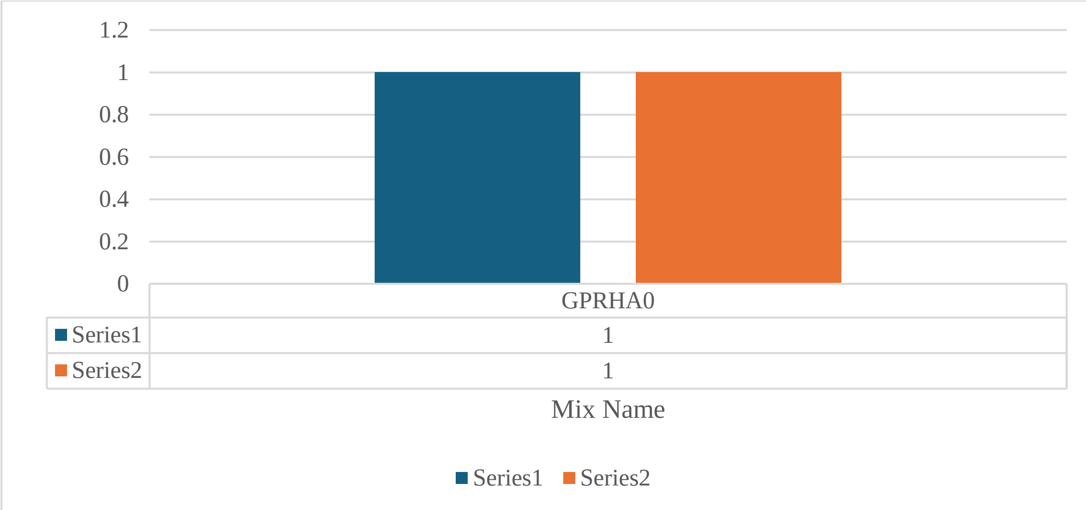

Fig. 8 Setting times for geopolymer concrete with rice husk Ash

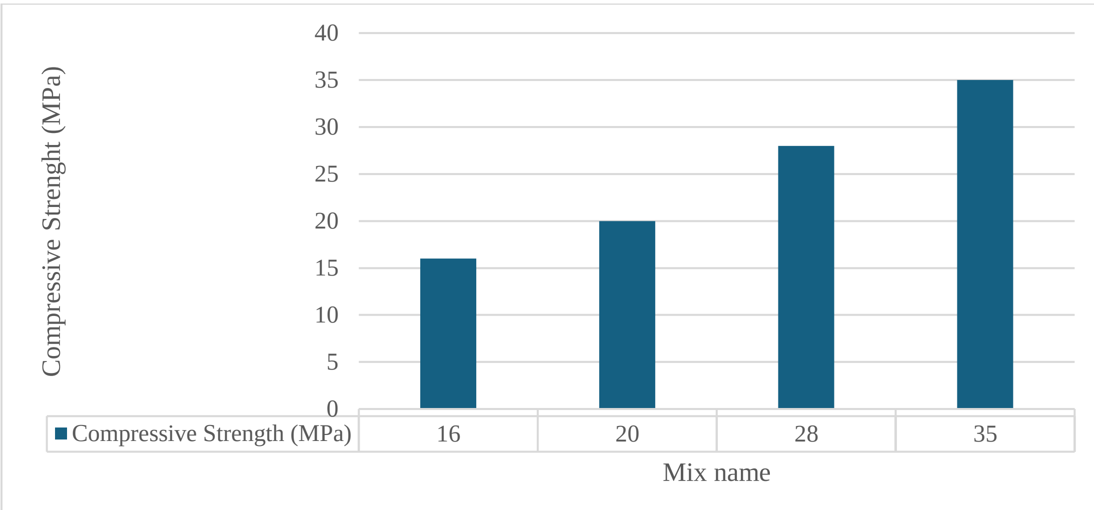

Fig. 9 Compressive strength of geopolymer concrete with rice husk Ash

Table 7 outlines the setting times for geopolymer concrete mixes with varying proportions of rice husk ash (RHA) to fly ash (FA). The initial setting time refers to the period when the concrete begins to harden, while the final setting time marks when the concrete has fully set.

For the mix GPRHA0, which contains no rice husk ash (0/100 RHA/FA ratio), the initial and final setting times are the longest, recorded at 260 minutes and 490 minutes, respectively. This indicates a slower hardening process, providing a longer working time before the concrete begins to set.

As the RHA content increases, the setting times decrease, indicating a faster setting process. For GPRHA1, with a 10% RHA content (10/90 RHA/FA ratio), the initial setting time drops to 220 minutes, and the final setting time decreases to 440 minutes. This trend continues with GPRHA2, where a 20% RHA content (20/80 RHA/FA ratio) results in an initial setting time of 190 minutes and a final setting time of 400 minutes. The fastest setting times are observed in GPRHA3, which has the highest RHA content at 30% (30/70 RHA/FA ratio), with an initial setting time of 160 minutes and a final setting time of 360 minutes.

Figure 8 visually illustrates these setting times, showing a clear inverse relationship between the RHA content and the duration of both initial and final setting times. As the RHA content increases, the setting times decrease, indicating that higher proportions of rice husk ash accelerate the setting process of geopolymer concrete.

This quicker hardening process may influence the scheduling and timing of construction activities, as well as the overall workability of the concrete during placement.

Table 8. Compressive strength of geopolymer concrete with rice husk ash

Mix Name	RHA/FA Ratio	Compressive Strength (MPa)
GPRHA0	0/100	16
GPRHA1	10/90	20
GPRHA2	20/80	28
GPRHA3	30/70	35

Table 8 provides the compressive strength values for geopolymer concrete mixes with varying ratios of Rice Husk Ash (RHA) to Fly Ash (FA). Compressive strength is a critical indicator of concrete's ability to withstand axial loads and is a key determinant of its structural performance. For the GPRHA0 mix, which contains no rice husk ash (0/100 RHA/FA ratio), the compressive strength is recorded at 16 MPa. This serves as the baseline strength for geopolymer concrete without RHA. As the RHA content increases, a notable improvement in compressive strength is observed. The GPRHA1 mix, with a 10/90 RHA/FA ratio, shows an increase in compressive strength to 20 MPa, indicating that even a small addition of RHA positively affects the concrete's strength.

Further increasing the RHA content to 20%, as seen in the GPRHA2 mix, results in a compressive strength of 28 MPa. This significant rise in strength suggests that RHA contributes greatly to the overall performance of the geopolymer concrete. The highest compressive strength is recorded in the GPRHA3 mix, where 30% of the fly ash is replaced with rice husk ash. This mix achieves a compressive strength of 35 MPa, demonstrating that including RHA substantially enhances the concrete's ability to resist compressive forces. Overall, the data in Table 6 and Figure 9 illustrate a clear trend: increasing the proportion of rice husk ash in geopolymer concrete leads to significant gains in compressive strength, with the highest strength observed at the maximum RHA content.

Table 9. Splitting tensile strength of geopolymer concrete with rice husk ash

Mix Name	RHA / FA Ratio	Splitting Tensile Strength (MPa)
GPRHA0	0/100	1.3
GPRHA1	10/90	1.8
GPRHA2	20/80	2.3
GPRHA3	30/70	2.6

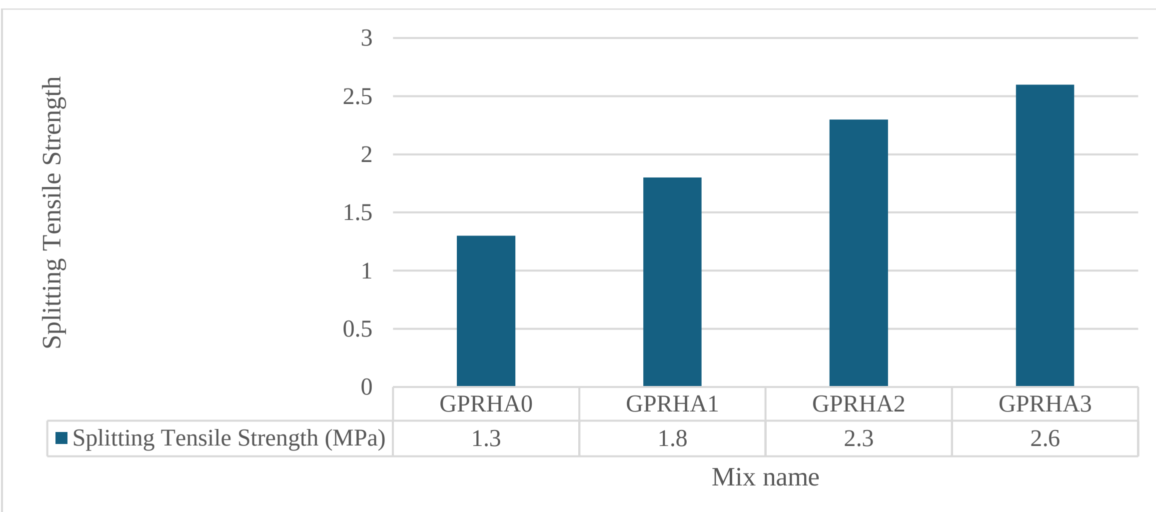

Fig. 10 Splitting Tensile Strength of Geopolymer Concrete with Rice Husk Ash

Table 9 provides splitting tensile strength test values for geopolymer concrete mixes with different ratios of Rice Husk Ash (RHA) to Fly Ash (FA), highlighting the material's ability to resist tensile stresses. The GPRHA0 mix contains no RHA (0/100 RHA/FA ratio) and has the lowest tensile strength at 1.3 MPa. As RHA is introduced into the mix, a marked improvement in tensile strength is observed. In the GPRHA1 mix, with a 10/90 RHA/FA ratio, the tensile strength increases to 1.8 MPa, showing that even a small amount of RHA positively impacts the tensile properties of the concrete. The GPRHA2 mix, with a 20/80 RHA/FA ratio, further enhances the tensile strength to 2.3 MPa, indicating that increasing RHA content strengthens the material. The highest tensile strength is recorded in the GPRHA3 mix, where 30% of the FA is replaced with RHA, achieving a tensile strength of 2.6 MPa.These results, as depicted in Figure 10, demonstrate a clear trend of increasing tensile strength with higher RHA content, underscoring the beneficial role of rice husk ash in improving the tensile performance of geopolymer concrete.

In addition to its ability to increase concrete's strength, the findings show that RHA might be a greener alternative to traditional methods of making the material. As a waste product from rice milling, RHA is an environmentally benign substitute for conventional supplemental materials and helps cut down on trash. Finding the sweet spot between RHA strength, workability, and setting times should be the goal of future studies. To further understand its potential use in different building contexts, it is essential to study the performance and longevity of RHA-blended GPC in various environments.

As part of this process, we must investigate how well the material withstands various types of deterioration, such as chemical attacks and freeze-thaw cycles. More research into these areas will help prove that RHA is useful for eco-friendly building methods and can improve geopolymer concrete's performance and environmental impact.

4. Conclusion

The study also highlights that incorporating Rice Husk Ash (RHA) in Geopolymer Concrete (GPC) contributes to its sustainability by utilizing agricultural waste, thus reducing the environmental footprint associated with concrete production. The enhanced mechanical properties, such as increased compressive and tensile strengths, suggest that RHA not only compensates for the reduced workability but also improves the overall durability and longevity of the concrete. Additionally, the accelerated setting times, while posing a challenge in terms of workability, may be advantageous in specific construction scenarios where rapid strength gain is desirable. The use of RHA in GPC aligns with the growing demand for green building materials and underscores its potential to advance sustainable construction practices. Despite the need for adjustments in mix design and handling, the benefits of RHA in improving the structural performance and sustainability of GPC make it a promising alternative to conventional concrete materials.

Recommendations

1. RHA Content Optimization: Future studies should investigate how to best balance the RHA content to provide better mechanical characteristics, workability, and setting times. Possible solutions to the problems with workability and setting times include experimenting with different RHA/FA ratios, adding chemical admixtures, or using other curing techniques.
2. Research on the performance and longevity of RHA-blended GPC is crucial. To guarantee its appropriateness for various building applications, further research should investigate how well RHA-enhanced GPC withstands environmental conditions such as chemical assaults, freeze-thaw cycles, and other types of deterioration.
3. 3. Mix Design Standardization: To achieve consistent quality and performance, it is helpful to develop defined methods for producing and curing RHA-blended GPC. In order to guarantee consistent and repeatable outcomes across several projects, it is necessary to establish best practices for mix design, handling, and curing.
4. 4. Investigation of Other By-Products: Studies should investigate the feasibility and effectiveness of including more industrial by-products, like slag and recycled aggregates, into GPC with RHA. Improving GPC's sustainability and cost-effectiveness can be achieved by understanding the interactions between these materials and RHA.
5. Evaluating the Environmental and Economic Consequences: In order to thoroughly examine the environmental and economic consequences of RHA-blended GPC, it is necessary to do comprehensive Life-Cycle Evaluations (LCA) and cost-benefit analyses. For a more complete picture of RHA's overall sustainability in GPC, these evaluations should take into account the full production cycle, from sourcing raw materials to disposal at the end of life.

In order to improve the overall efficiency and resilience of concrete buildings, future research should address these recommendations and progress the development of GPC technologies. This will promote their widespread application in sustainable construction practices.

References

[1] Chandan Kumar Patnaikuni, and Malleswara Rao Palli, *Rice Husk Ash Influence in Cement Concrete*, Lulu Publication, pp. 1-173, 2021. [Google Scholar] [Publisher Link]

[2] A.A. Ramezanianpour, M. Mahdi Khani, and Gh. Ahmadibeni, "The Effect of Rice Husk Ash on Mechanical Properties and Durability of Sustainable Concretes," *International Journal of Civil Engineering*, vol. 7, no. 2, pp. 83-91, 2009. [Google Scholar] [Publisher Link]

[3] Peem Nuaklong et al., "Influence of Rice Husk Ash on Mechanical Properties and Fire Resistance of Recycled Aggregate High-Calcium Fly Ash Geopolymer Concrete," *Journal of Cleaner Production*, vol. 252, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[4] M. Jamil et al., "Physical and Chemical Contributions of Rice Husk Ash on the Properties of Mortar," *Construction and Building Materials*, vol. 128, pp. 185-198, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[5] K. Sakr, "Effects of Silica Fume and Rice Husk Ash on the Properties of Heavy Weight Concrete," *Journal of Materials in Civil Engineering*, vol. 18, no. 3, pp. 367-376, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[6] Agbede Olufemi et al., "Production of Concrete Roofing Tiles Using Rice Husk Ash (RHA) in Partial Replacement of Cement," *International Research Journal of Engineering and Technology*, vol. 3, no. 6, pp. 2678-2685, 2016. [Google Scholar] [Publisher Link]

[7] K. Ganesan, K. Rajagopal, and K. Thangavel, “Rice Husk Ash Blended Cement: Assessment of Optimal Level of Replacement for Strength and Permeability Properties of Concrete,” *Construction and Building Materials*, vol. 22, no. 8, pp. 1675-1683, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[8] Ghassan Abood Habeeb, and Hilmi Bin Mahmud, “Study on Properties of Rice Husk Ash and its Use as Cement Replacement Material,” *Materials Research*, vol. 13, no. 2, pp. 185-190, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[9] Le Anh-tuan Bui et al., “Effect of Silica Forms in Rice Husk Ash on the Properties of Concrete,” *International Journal of Minerals, Metallurgy, and Materials*, vol. 19, pp. 252-258, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[10] Michael Toryila Tiza, “Sustainability in the Civil Engineering and Construction Industry: A Review,” *Journal of Sustainable Construction Materials and Technologies*, vol. 7, no. 1, pp. 30-39, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[11] Qingge Feng et al., “Study on the Pozzolanic Properties of Rice Husk Ash by Hydrochloric Acid Pretreatment,” *Cement and Concrete Research*, vol. 34, no. 3, pp. 521-526, 2004. [CrossRef] [Google Scholar] [Publisher Link]

[12] Rahmat Madandoust et al., “Mechanical Properties and Durability Assessment of Rice Husk Ash Concrete,” *Biosystems Engineering*, vol. 110, no. 2, pp. 144-152, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[13] Sachin Singh, and Abhilash Shukla, “Effect of Rice Husk Ash on the Properties of Concrete,” *International Journal for Research in Applied Science & Engineering Technology*, vol. 11, no. 10, pp. 1056-1062, 2023. [CrossRef] [Publisher Link]

[14] Mahdi Koushkbaghi et al., “Acid Resistance and Durability Properties of Steel Fiber-Reinforced Concrete Incorporating Rice Husk Ash and Recycled Aggregate,” *Construction and Building Materials*, vol. 202, pp. 266-275, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[15] Kishor Chandra Panda, Subhrasweta Behera, and Shradha Jena, “Effect of Rice Husk Ash on Mechanical Properties of Concrete Containing Crushed Seashell as Fine Aggregate,” *Materials Today: Proceedings*, vol. 32, no. 4, pp. 838-843, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[16] Md. Safiuddin, J.S. West, and K.A. Soudki, “Hardened Properties of Self-Consolidating High Performance Concrete Including Rice Husk Ash,” *Cement and Concrete Composites*, vol. 32, no. 9, pp. 708-717, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[17] Ali Nazari, Ali Bagheri, and Shadi Riahi, “Properties of Geopolymer with Seeded Fly Ash and Rice Husk Bark Ash,” *Materials Science and Engineering: A*, vol. 528, no. 24, pp. 7395-7401, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[18] J. Sutas, A. Mana, and L. Pitak, “Effect of Rice Husk and Rice Husk Ash to Properties of Bricks,” *Procedia Engineering*, vol. 32, pp. 1061-1067, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[19] Michael Toryila Tiza et al., “Integrating Sustainability into Civil Engineering and the Construction Industry,” *Journal of Cement Based Composites*, vol. 4, no. 1, pp. 1-11, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[20] Aysegul Petek Gursel, Helena Maryman, and Claudia Ostertag, “A Life-Cycle Approach to Environmental, Mechanical, and Durability Properties of “Green” Concrete Mixes with Rice Husk Ash,” *Journal of Cleaner Production*, vol. 112, no. 1, pp. 823-836, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[21] Seyed Mahmoud Zabihi, Hamidreza Tavakoli, and Ehsan Mohseni, “Engineering and Microstructural Properties of Fiber-Reinforced Rice Husk Ash Based Geopolymer Concrete,” *Journal of Materials in Civil Engineering*, vol. 30, no. 8, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[22] Bharat Bhushan Jindal, Parveen Jangra, and Atul Garg, “Effects of Ultra Fine Slag as Mineral Admixture on the Compressive Strength, Water Absorption and Permeability of Rice Husk Ash Based Geopolymer Concrete,” *Materials Today: Proceedings*, vol. 32, no. 4, pp. 871-877, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[23] Andri Kusbiantoro et al., “The Effect of Microwave Incinerated Rice Husk Ash on the Compressive and Bond Strength of Fly Ash Based Geopolymer Concrete,” *Construction and Building Materials*, vol. 36, pp. 695-703, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[24] Koti Chiranjeevi, M.M. Vijayalakshmi, and T.R. Praveenkumar, “Investigation of Fly Ash and Rice Husk Ash-Based Geopolymer Concrete Using Nano Particles,” *Applied Nanoscience*, vol. 13, pp. 839-846, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[25] Toryila Michael Tiza et al., “Assessing the Potentials of Bamboo and Sheep Wool Fiber as Sustainable Construction Materials: A Review,” *Materials Today: Proceedings*, vol. 47, no. 14, pp. 4484-4489, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[26] Ankur Mehta, and Rafat Siddique, “Sustainable Geopolymer Concrete Using Ground Granulated Blast Furnace Slag and Rice Husk Ash: Strength and Permeability Properties,” *Journal of Cleaner Production*, vol. 205, pp. 49-57, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[27] Saraswati Verma, and Mayank Kumar, “Behaviour of Fly Ash and Rice Husk Ash Based Geopolymer Concrete,” *Key Engineering Materials*, vol. 775, pp. 596-602, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[28] Yamini J. Patel, and Niraj Shah, “Enhancement of the Properties of Ground Granulated Blast Furnace Slag Based Self Compacting Geopolymer Concrete by Incorporating Rice Husk Ash,” *Construction and Building Materials*, vol. 171, pp. 654-662, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[29] Shaswat Kumar Das et al., “Characterization and Utilization of Rice Husk Ash (RHA) in Fly Ash – Blast Furnace Slag Based Geopolymer Concrete for Sustainable Future,” *Materials Today: Proceedings*, vol. 33, no. 8, pp. 5162-5167, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[30] R. Prasanna Venkatesan, and K.C. Pazhani, “Strength and Durability Properties of Geopolymer Concrete made with Ground Granulated Blast Furnace Slag and Black Rice Husk Ash,” *KSCE Journal of Civil Engineering*, vol. 20, pp. 2384-2391, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[31] Mahapara Abbass, and Gyanendra Singh, “Impact Strength of Rice Husk Ash and Basalt Fibre Based Sustainable Geopolymer Concrete in Rigid Pavements,” *Materials Today: Proceedings*, vol. 61, no. 2, pp. 250-257, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[32] Mahapara Abbass, and Gyanendra Singh, “Durability of Rice Husk Ash and Basalt Fibre Based Sustainable Geopolymer Concrete in Rigid Pavements,” *Materials Today: Proceedings*, vol. 61, no. 2, pp. 558-570, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[33] Ramesh Kumar Chouhan et al., “Rice-Husk-Based Superplasticizer to Increase Performance of Fly Ash Geopolymer Concrete,” *Emerging Materials Research*, vol. 7, no. 3, pp. 169-177, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[34] Z.A. Alrowaili et al., “Radiation Attenuation of Fly Ash and Rice Husk Ash-Based Geopolymers as Cement Replacement in Concrete for Shielding Applications,” *Radiation Physics and Chemistry*, vol. 217, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[35] Chao-Lung Hwang, and Trong-Phuoc Huynh, “Effect of Alkali-Activator and Rice Husk Ash Content on Strength Development of Fly Ash and Residual Rice Husk Ash-Based Geopolymers,” *Construction and Building Materials*, vol. 101, no. 1, pp. 1-9, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[36] Mariam Abdulkareem et al., “Environmental and Economic Perspective of Waste-Derived Activators on Alkali-Activated Mortars,” *Journal of Cleaner Production*, vol. 280, no. 1, pp. 1-11, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[37] Subhashree Samantasinghar, and Suresh Prasad Singh, “Fresh and Hardened Properties of Fly Ash–Slag Blended Geopolymer Paste and Mortar,” *International Journal of Concrete Structures and Materials*, vol. 13, pp. 1-12, 2019. [CrossRef] [Google Scholar] [Publisher Link]