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Utilizing Fly Ash And Rice Husk Ash In Geopolymer Concrete: A Comparative Performance Study

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Abstract

Environmental concerns stemming from cement production have emerged as a significant issue today. In pursuit of a sustainable future, there is a growing importance on reducing the use of this construction material due to its environmental impact. Geopolymer represents a promising alternative to traditional cement. Geopolymer concrete (GPC) is a hardened cementitious paste composed of alkaline solution, fly ash, fine and coarse aggregates. This research focusedto assessthe impact of utilizing rice husk ash (RHA) as a partial replacement of FA in GPC. The addition of RHA, serving as a source of silica, significantly influenced the strength of GPC.[1] The research discovered that the suitability of GPC diminishes as the amount of RHA increases, although it still stays within acceptable bounds. The inclusion of RHA in GPC resulted in higher compressive strength, tensile strength, and flexural strength. Also, the inclusion of RHA was found to be increased the acid resistance of GPC. Higher silica content correlates with increased strength and enhanced durability.

***Keywords**: Acid resistance, Alkaline activators, Fly ash, Geopolymer concrete, Rice husk ash, Strength, Workability.*

1. Introduction

Davidovits discovered the geopolymerization process and, eleven years later, invented high-strength geopolymer cement. This innovative material does not require Portland cement to achieve its strength. His research indicated that geopolymer production depends on raw materials containing alumina (Al_2O_3) and silica (SiO_2) to form strong Si-O-Al bonds. Following this, researchers found that fly ash, which also contains SiO_2 and Al_2O_3, could be used as a binder.The term "Geopolymer," coined by Davidovits, describes these binders due to the polymerization process involved (Davidovits, 1994). Geopolymer concrete, which excludes Portland cement, is currently under extensive study and shows promise as an alternative to traditional cement. The research focus has shifted from basic chemistry to engineering applications and commercial production. Geopolymers consist mainly of two ingredients: source materials and alkaline liquids. Rich sources of silicon and aluminum are the best materials for alumina-silicate geopolymers. According to Bakharev (2005), various industrial by-products like rice husk ash (RHA), fly ash, slag, and silica fume, alongside natural resources such as clays and kaolinite, have potential applications. The source materials can be selected by considering some factors like cost, availability etc. The alkaline

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liquids used in geopolymerization typically contain soluble alkali metals, predominantly sodium or potassium-based. Common combinations include NaOH or KOH with Na_2SiO_3or K_2SiO_3 (Chagas Cordeiro et al., 2009).

Rice husk ash (RHA) is well-known for its non-crystalline silica content. Burning rice husks under controlled conditions yields a very reactive pozzolanic material. Under different conditions, lower-quality "residual RHA" is produced, often containing residual carbon and some crystalline silica, which increases water demand. However, grinding residual RHA to the appropriate particle size can enhance its quality, despite the high cost (Anderson and Moore, 2020). This study examines how RHA impacts the characteristics of fly ash-based geopolymer concrete.

2. Materials and Methods

2.1 Fly ash (FA)

Coal-fired power plants produce several secondary materials as a result of their operation. These include fly ash, which consists of fine particles that are carried up the chimney along with the combustion gases. Boiler slag is another byproduct, formed from melted ash particles that adhere to the walls of the boiler. Bottom ash, on the other hand, is the larger, heavier particles that settle to the bottom of the combustion chamber. Lastly, there is flue gas desulfurization sludge, which forms from the treatment of the sulfur dioxide-rich flue gases to reduce emissions. These materials require proper management to mitigate environmental impacts effectively. Blended cement is made mostly from these byproducts. The tiny, spherical alumina-silicate particles that make up fly ash, which makes up 75–80% of the overall ash mass, are usually collected from the power plant's chimney(Harris and Green, 2016; Lee and Clark, 2015). The kind of coal used to create fly ash determines its chemical makeup. Bituminous and older geological coals, such as anthracite, produce ASTM kind F fly ash, which is low in calcium and functions as a pozzolan. The calcium-rich ASTM Type C fly ash, on the other hand, is produced by younger geological coals, such as lignite or sub-bituminous coals, and it can have cementitious qualities when it comes into contact with water without an activator(Wright and Turner, 2014; King and Evans, 2013). Lesser elements' chemical composition is also influenced by the kind of coal, and there are notable differences in this regard between samples taken from various locations within the same coal seam as well as between different types of coal.(Adams and Rivera, 2012).

Like slag, recycling fly ash has three main advantages for the environment: it lowers greenhouse gas emissions, lowers the demand for virgin resources used to make Portland cement, and uses less energy in the processing of those virgin materials(Stewart and Torres, 2011; Mitchell and Foster, 2010).

2.2 Rice husk ash (RHA)

A byproduct of rice processing is rice husk ash (RHA). The indigestible outer husk of rice makes up around 20% to 25% of the crop and is usually burnt in domestic stoves or local power facilities to provide steam for rice parboiling. When burnt, around 18% of these husks become ash. Consequently, one ton of rice generates around 45 kg of RHA, which has a large surface area, substantial pozzolanic characteristics, and is mostly made of silica (about 95%). RHA's amount, chemical makeup, and crystalline content are significantly influenced by furnace design and burning temperatures. Specifically, breathing in crystalline silica in RHA can be dangerous. (Hughes and Diaz, 2006).

Rice, being a staple crop globally, generates a substantial volume of Rice Husk Ash (RHA) annually. Despite corn surpassing rice in total production due to its diverse non-food applications, the sheer scale of rice cultivation ensures a significant RHA output. Countries like China, India, Indonesia, and Bangladesh are among the largest producers, with estimated annual outputs of 7.2 million metric tons (Mt), 5.5 Mt, 2.2 Mt, and 1.7 Mt respectively. It's approximated that about 3.5% of the weight of rice ultimately becomes RHA. Consequently, the total potential global production of RHA is estimated at approximately 20 Mt annually, highlighting its substantial presence in agricultural and industrial contexts worldwide (Prabu and Shalini, 2014).

In Asia, where rice cultivation is predominant, rice husk ash (RHA) is widely available, but transportation remains a significant challenge. Many rural areas lack modern combustion facilities, relying instead on open-field burning which produces lower-quality RHA alongside significant CO2 emissions and pollution. Limited awareness and acceptance of RHA's potential applications remain significant barriers, compounded by its often dark (typically black) color which raises aesthetic concerns (Cooper and Martinez, 2004).

Table 1 presents the chemical compositions of FA and RHA used in this study. Table 2 details the properties of fine and coarse aggregates employed in this research.

Table 1: Composition of materials in terms of their chemistry

Materials	Chemical compositions (%)								
	SiO_2	CaO	MgO	Na_2O	K_2O	Al_2O_3	Fe_2O_3	SO_3	LOI
RHA	85.2	0.75	0.55	0.05	3.6	1.15	1.16	0.32	5.51
FA	51.2	2.24	1.43	0.78	2.38	29.1	9.2	0.26	3.41

Table 2: Characteristics of Fine Aggregates and Coarse Aggregates

Properties	Fine Aggregate	Coarse Aggregate (10mm)	Coarse Aggregate (20mm)
Sp. Gravity	2.54	2.65	2.72
Bulking (%)	13.64	-	-
Silt Content (%)	3.92	-	-
Water Abs. (%)	0.80	0.89	0.35

2.3 Alkaline Activators

The commonly used alkaline activators include a combination of NaOH or KOH with Na_2SiO_3 or K_2SiO_3. It has been observed that alkaline-activated slag exhibits improved mechanical strength with higher concentrations of activators. Furthermore, a comparative study on the geopolymerization of 16 natural aluminum-silicate (Al-Si) minerals showed that NaOH generally leads to greater mineral dissolution than KOH(Thompson and Garcia, 2019).In this study, a solution consisting of Na_2SiO_3 and NaOH pellets with a purity of 99.42% was used. The Na_2SiO_3 solution contained 56% water by weight, with a silica-to-sodium oxide ratio of 2:1 (SiO_2/Na_2O ratio).

2.4 Super Plasticizer

In order to enhance the workability of newly mixed concrete, superplasticizers were added to the mix. This additive enhances workability by reducing the need for additional water, which minimizes the risk of segregation. Even when used in excess, it ensures normal setting and a smooth surface finish. Notably, being chloride-free, it does not pose a risk to reinforcement or prestressed cables if present.In this study, modified polycarboxylate-based superplasticizers (SPs) were used. The features of superplasticizers (SPs), sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) are given in Table 3.

Table 3: Characteristics of NaOH, Na_2SiO_3 and SPs

Characteristics	SPs	NaOH	Na_2SiO_3
Specific gravity (25°C)	1.05		
pH (25°C)	4.5		
Cl (%)	0.1		
Alkalinity (%)	0.3		
NaOH (% by mass)		99.4	
Cl (% by mass)		0.12	
Na_2CO_3 (% by mass)		0.44	
Sp. Gravity	-		1.54
Na_2O (%)	-		13.85
SiO_2 (%)	-		30.35
H_2O (%)	-		55.20

2.5 Preparation of alkaline solution

In this study, a 14M NaOH solution was meticulously prepared by dissolving 560 grams of NaOH pellets in 1000 milliliters of distilled water. This step is critical and requires careful handling due to the exothermic nature of the reaction between sodium hydroxide (NaOH) and water, which generates heat. To ensure safety and proper conditions for the experiment, the solution was allowed to cool naturally to room temperature, a process that took approximately one day.

2.6 Ratio of ingredients in GPC

Drawing on pertinent research, the study focused on determining the ideal mix ratios to evaluate how rice husk ash (RHA) affects the engineering characteristics of geopolymer concrete (GPC) based on fly ash (FA). The research experimentally varied the proportions of RHA to FA in the concrete mixes while keeping the sodium hydroxide (NaOH) concentration constant at 14M. This consistency in NaOH concentration ensured a standardized alkaline environment across all experimental formulations.

Additionally, the liquid-to-binder ratio (L/B), which plays a crucial role in the workability and final properties of geopolymer concrete, was set at 2 for all mixtures. Similarly, the ratio of sodium silicate (Na2SiO3) solution to NaOH solution (SS) was maintained at a constant value of 2 throughout the study. These standardized parameters provided a controlled framework for assessing the specific influence of varying RHA content on the geopolymerization process and the resulting properties of the concrete.

By systematically varying the RHA to FA ratios under these controlled conditions, the study aimed to identify optimal compositions that could potentially enhance the performance and sustainability of fly ash-based geopolymer concrete, offering valuable insights for future applications in construction and materials engineering.

Each mix contained 400 kg/m³ of binder, which included both FA and RHA. Fine and coarse aggregates collectively accounted for about 3% of the binder in all formulations. In each mix, 0.5% of superplasticizers (SPs) were added. Table 4 provides the specific mix proportions for the geopolymer concrete formulations.

Table 4: Mix proportions of FA-RHA based GPC

Mix Name	Proportions of the mixture			Quantity of mixture (kg/m^3)							
	RHA/FA	L/B ratio	SS/SH	FA	RHA	SH	SS	SPs	Fine Aggregat	CA 10	CA 20

			ratio						e	mm	mm
GPRHA0	00/100	0.45	2	40 0	00	60	12 0	2	600	400	800
GPRHA1	10/90	0.45	2	36 0	40	60	12 0	2	600	400	800
GPRHA2	20/80	0.45	2	32 0	80	60	12 0	2	600	400	800
GPRHA3	30/70	0.45	2	28 0	120	60	12 0	2	600	400	800
FA (Fly Ash); RHA (Rice Husk Ash); SH (Sodium Hydroxide); SS (Sodium Silicate); SPs (Superplasticizers); CA (Coarse Aggregates). Liquid to binder (L/B) ratio											

2.7 Preparation of Specimens and Testing methods

In this study, specimens of fly ash (FA) and rice husk ash (RHA) geopolymer concrete were meticulously prepared using a procedure similar to conventional cement concrete methods. Initially, FA, RHA, fine aggregates, and coarse aggregates underwent a thorough two-minute dry mixing to ensure homogeneity. Subsequently, superplasticizers and a basic solution were introduced, followed by an additional three minutes of stirring to achieve optimal workability. The freshly mixed concrete was then cast into standardized molds: 100 mm cubes for compression tests, 100x200 mm cylinders for split tensile tests, and 100x100x500 mm prisms for four-point flexural tests. To ensure consistency, each combination was replicated in three specimens. After casting, the specimens underwent a 24-hour initial curing period in an environment maintained at approximately 23°C and 70% relative humidity. They were subsequently demoulded and transferred to a curing chamber set at 20°C and 90% relative humidity until readiness for testing. The comprehensive evaluation encompassed assessments of workability, compressive strength, splitting tensile strength (STS), flexural strength (FS), as well as acid and sulfate resistance, all conducted in accordance with ASTM standards to ensure rigorous and standardized testing protocols.

3. Result and Discussion

3.1 Workability

GPC is not as easily manipulated as OPC because it contains a higher amount of silicates, resulting in a higher level of stickiness. Even with its minimal slump, geopolymer concrete can still be efficiently compacted with a vibrating table. For geopolymer concrete, slump values of 90 millimeters or higher indicate high workability. Medium workability is defined by slump values between 50 and 89 mm, while slump values below 50 mm indicate poor workability. The study identified a geopolymer concrete mix that meets these workability criteria. Figure 1 depicts the relationship between the slump value of geopolymer concrete and the substitution of RHA. Interestingly, contrary to expectations, increasing the concentration of RHA leads to lower slump values.

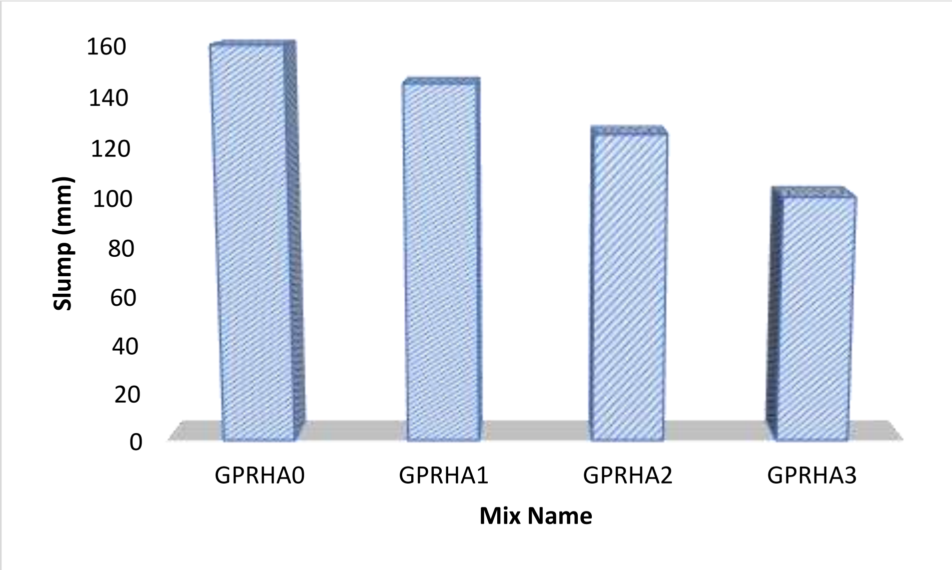

Fig. 1. Effect of different RHA contents on workability of geopolymer concrete

3.2 Strength

Compressive strength stands as a fundamental and pivotal characteristic of concrete, universally acknowledged for its role in quality assurance and performance assessment. Several factors influence the strength of concrete, encompassing the types and quality of materials used, proportions of the mix, methods of construction, conditions during curing, and methodologies employed in testing. At a microscopic level, the extent of hydration and the porosity of the concrete are crucial determinants of its strength. Increased porosity generally correlates with decreased strength due to the presence of more voids within the material. Moreover, a lower binder/space ratio, which quantifies the ratio of the calcium-silicate-hydrate (C-S-H) gel content to the initial volume of voids, serves to augment concrete strength by optimizing the packing of materials within the mix. These insights underscore the complex interplay of factors influencing concrete strength and highlight the importance of meticulous design and testing protocols in ensuring durable and resilient construction materials.

Figure 2 illustrates the compressive strength characteristics of geopolymer concrete specimens as affected by varying levels of rice husk ash (RHA) replacement. Geopolymer concrete typically demonstrates accelerated strength development within the first 28 days of curing, followed by a more gradual increase thereafter. The extent of RHA replacement significantly impacts the compressive strength of the concrete, evident from the results presented. For instance, initial compressive strength measured at 28 days starts at 24 MPa and progressively increases to 35 MPa with an increase in RHA replacement from 10% to 30%. This trend underscores the role of RHA as a supplementary material in enhancing the mechanical properties of geopolymer concrete, reflecting its potential to optimize performance in construction applications through tailored mix designs and material substitutions.

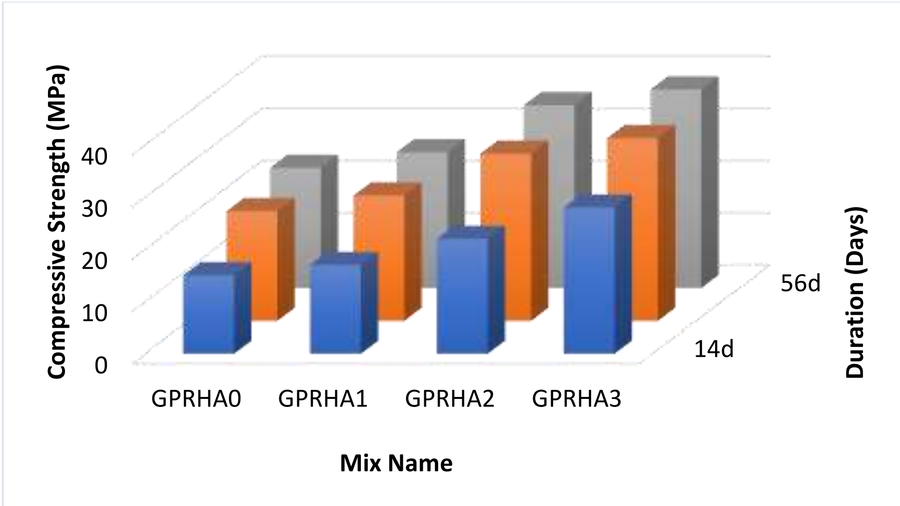

Fig. 2 Effect of Different Levels of RHA on the Compressive Strength of Geopolymer Concrete

Figure 3 visually represents the influence of rice husk ash (RHA) on the 28-day split tensile strength (STS) and flexural strength (FS) of fly ash-based geopolymer concrete. The findings depicted in the figure highlight a positive correlation between higher RHA content and enhanced split tensile and flexural strengths of the concrete specimens. Specifically, as the percentage of RHA replacement increases, there is a noticeable improvement in both split tensile strength and flexural strength at the 28-day curing period. This indicates that incorporating RHA into the geopolymer mix contributes to the overall mechanical performance of the concrete, suggesting its potential as a beneficial additive for achieving superior tensile and flexural properties in geopolymer-based construction materials. These results underscore the importance of optimizing RHA content in geopolymer concrete formulations to achieve desired strength characteristics tailored to specific engineering applications.

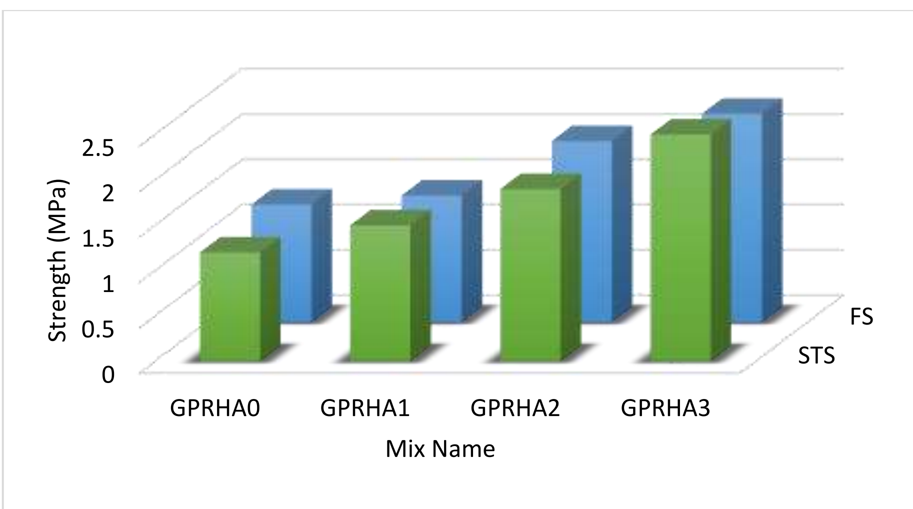

Fig. 3. Split tensile strength (STS) and flexural strength (FS) of geopolymer concrete were evaluated at different levels of RHA content over a 28-day period.

3.3 Acid Resistance

The effect of rice husk ash (RHA) on the chemical durability of concrete was assessed following ASTM C267 standards. Mortar cylinders of dimensions 50x100 mm were prepared and initially weighed in a saturated surface dry (SSD) state after undergoing 7 days of moist curing at 20°C and 100% relative humidity. Subsequently, these cylinders were immersed in a 1% hydrochloric acid (HCl) solution to simulate aggressive chemical exposure conditions. The ASTM C267 guidelines were followed to monitor and evaluate the mass loss of the specimens over a specified period in the acidic environment. This experimental setup aims to investigate how the inclusion of RHA in concrete formulations affects its resistance to chemical degradation, providing insights into the material's potential durability and suitability for applications exposed to corrosive environments. Throughout the test period, the cylinders were cleaned weekly by rinsing them three times with cold running tap water and then quickly drying them by blotting with paper towels. The mass was recorded within 30 minutes after each preparation. The hydrochloric acid solution was replaced every week before placing the cylinders back in, and mass measurements were recorded for a maximum of 56 days.

Figure 4 depicts the percentage of mass loss over time for various mixes of geopolymer concrete. It was observed that mass loss increased with longer exposure durations across all mixes of geopolymer concrete. Additionally, it was found that increasing the RHA content led to a reduction in mass loss.

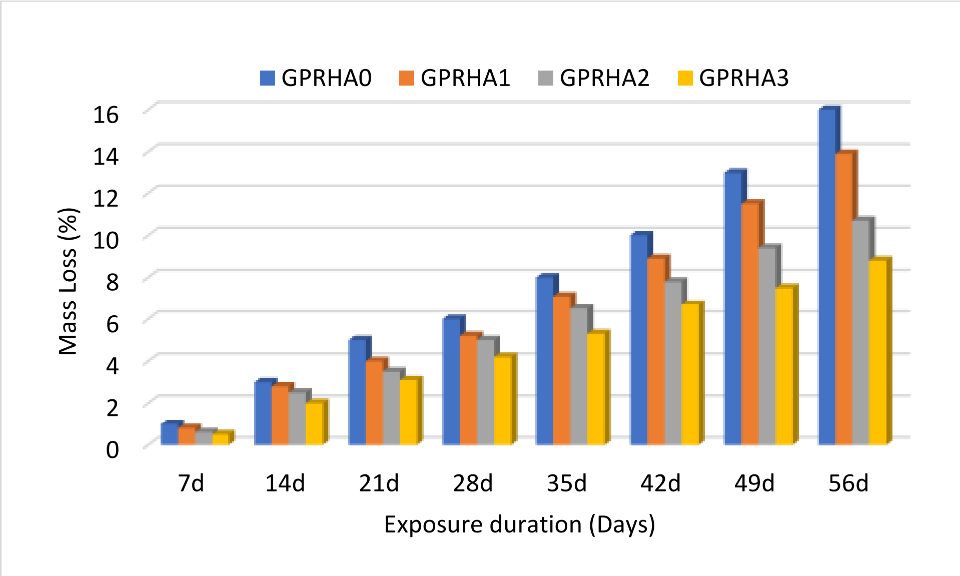

Fig. 4. Mass loss (%) with exposure duration

4. Conclusion

This study investigates the influence of rice husk ash (RHA) on the properties of geopolymer concrete formulated with fly ash. It underscores the significant potential impact that RHA-based geopolymer concrete is poised to have within the construction industry. RHA offers a cost-effective and innovative solution for managing hazardous residues in stringent environmental contexts. Geopolymer concrete has shown promising characteristics as a sustainable building material, highlighting its potential for reducing carbon footprint compared to traditional cement-based concrete.

The research also identifies several areas that require further investigation to broaden the applicability of geopolymer concrete. Incorporating RHA into fly ash geopolymer concrete is increasingly crucial as it aligns with environmental regulations and the demand for durable construction materials.

- Adding rice husk ash (RHA) to fly ash-based geopolymer concrete reduced its workability due to RHA's increased specific surface area and carbon content. Despite this, the slump value, indicating the concrete's fluidity and ease of placement, stayed within acceptable limits.
- Higher levels of rice husk ash (RHA) in fly ash-based geopolymer concrete resulted in notable enhancements across key strength parameters including compressive strength, split tensile strength (STS), and flexural strength (FS). For example, after 28 days, geopolymer concrete containing 30% RHA demonstrated a significant 66.67% increase in compressive strength compared to the control mixture.
- Specimens containing RHA demonstrated enhanced resistance to acid attacks in comparison to those without RHA.

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Conflict of Interest

The author(s) declares no conflict of interest.

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