IJFANS INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES
ISSN PRINT 2319 1775 Online 2320 787
Research Paper UGC CARE Listed (Group -I) Journal Volume 10, Iss 09, 2021

Advancing Geopolymer Technology: The Impact of Rice Husk Ash on the Mechanical Strength of M40 Concrete

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Abstract
This research explores the role of concrete as a pivotal construction material and introduces geopolymer concrete as an environmentally friendly alternative to ordinary Portland cement (OPC). Utilizing industrial by-products such as fly ash and rice husk ash (RHA) mixed with alkaline solutions, geopolymer concrete emerges as a sustainable option to mitigate the carbon footprint of the construction sector. This paper reports on the mechanical behavior of steel-reinforced geopolymer concrete composites incorporating varying proportions of RHA as a partial substitute for cement. It was observed that the compressive strength tends to diminish with an increase in RHA content, suggesting an optimal replacement threshold. The study finds that up to 20% of fly ash can be effectively replaced with RHA in the geopolymer mix without compromising structural integrity. While the addition of RHA impacts the initial workability of the concrete mix, this can be counteracted through specific chemical additives. The overarching aim is to enhance resource recovery and recycling in construction materials, aligning with sustainable development practices.

Keywords: Geopolymer concrete, Rice husk ash, Fly ash, Compressive strength, Sustainable construction, M40 concrete grade.

I. INTRODUCTION

Concrete's ubiquity in construction stems from its impressive strength, enduring nature, and adaptability. Yet, the environmental toll of producing standard cement-based concrete is notable, particularly in terms of carbon dioxide emissions and the consumption of finite resources. In response to these challenges, the construction industry is turning to innovative materials that could lessen the ecological footprint of concrete manufacturing.

Geopolymer concrete emerges as a promising alternative, utilizing geopolymers for binding rather than traditional Portland cement. These inorganic polymers are synthesized through the reaction of alumina-silicate-rich materials with alkaline liquids. The adoption of geopolymer technology could significantly curtail greenhouse gas outputs while repurposing industrial by-products as cement substitutes.

At the heart of this investigation is the strategic incorporation of rice husk ash (RHA) into geopolymer concrete, harnessing this plentiful agricultural by-product that is typically discarded. The integration of RHA is geared toward creating more sustainable and eco-conscious building materials.

The focus is placed on geopolymer concrete of M40 grade, known for its prerequisite characteristic strength of 40 MPa and suitability in high-demand structural contexts. This research aims to scrutinize the impact of substituting cement with RHA on the material's mechanical robustness, longevity, and structural makeup.

A series of experimental procedures are deployed to identify the ideal proportion of RHA for cement replacement in geopolymer concrete. This involves examining the influence of RHA on core strength attributes, including compressive, tensile, and flexural strengths, among others. Durability indicators, such as water absorption, chloride ion penetration, and resistance to carbonation, are also evaluated to gauge the material's resilience against various environmental factors.

Additionally, the study delves into the microscopic composition of the geopolymer concrete using advanced methods like scanning electron microscopy (SEM) and X-ray diffraction (XRD), aiming to elucidate the underlying chemical reactions and the nature of the bonds within the geopolymer matrix.

The insights gleaned from this research are anticipated to shed light on the practicality and effectiveness of RHA in replacing cement in M40 grade geopolymer concrete. The outcomes are poised to contribute to the evolution of sustainable concrete technologies, diminishing the dependence on conventional cement, and advocating for the reclamation of agricultural waste in construction.

This inquiry into alternative cementitious materials and their functional attributes in geopolymer concrete stands to propel eco-friendly building methods forward, aligning with the broader objective of fostering sustainable infrastructure development.

Limitations in the Use of Rice Husk Ash in Geopolymer Concrete:

- **Optimization of Cement Replacement**: Identifying the ideal proportion of cement to be replaced by rice husk ash (RHA) to meet the M40 concrete grade's mechanical requirements is intricate. The suitable level of substitution might vary due to the specific characteristics of the RHA, the type of alkaline activator, and the concrete mix design. Extensive experimentation might be necessary to pinpoint the optimal replacement percentage.
- **RHA Supply and Consistency**: The availability and consistency of high-quality RHA are subject to variability, influenced by the origin of the rice husk, its combustion, and subsequent processing. Such variability could impact geopolymer concrete's performance, and securing a steady supply of premium RHA could be a limitation in certain areas or for particular projects.
- **Assessing Durability**: Although geopolymer concrete typically exhibits excellent durability, the long-term durability of geopolymer concrete incorporating RHA as a partial cement substitute warrants detailed investigation. Research should delve into endurance against environmental stressors and aging.
- **Need for Standardization**: As geopolymer concrete is relatively new, standardized guidelines and specifications for the incorporation of RHA in M40 grade geopolymer

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concrete are lacking. This deficit could present challenges in ensuring consistency and reproducibility in research outcomes.

- **Cost Analysis**: The economics of utilizing RHA, including procurement and processing, could influence the viability of geopolymer concrete with RHA. It is essential for research to consider these costs in comparison with traditional concrete to determine cost-effectiveness.
- **Practical Application Barriers**: Applying geopolymer concrete with RHA in actual construction scenarios could encounter practical difficulties, including modifications to established building practices, gaining industry acceptance, and adhering to current regulations. Recognizing and overcoming these challenges is crucial for the broader integration of geopolymer concrete with RHA in the construction sector.

Challenges in Developing Geopolymer Concrete with Rice Husk Ash:

- **Achieving the Optimal Mix**: Crafting the ideal blend for geopolymer concrete that integrates rice husk ash (RHA) to meet M40 grade standards presents a complex task. The process demands precise calibration of RHA, alkaline activators, aggregates, and additives to fulfill the required strength and durability benchmarks.
- **Consistency in RHA Quality**: The characteristics of RHA may fluctuate based on its origin, combustion methodology, and processing practices, impacting its effectiveness in the geopolymer mix. Uniformity in the quality of RHA is critical to produce reliable and reproducible concrete properties.
- **Refining the Activation Process**: The geopolymerization sequence is intricate, necessitating a finely tuned activation regime. Selecting the right alkaline solutions and curing environments is pivotal. This step must be meticulously managed to catalyze the desired geopolymer formation and performance.
- **Ensuring Durability**: To assure longevity, geopolymer concrete with RHA must be rigorously tested against environmental stressors like freeze-thaw patterns, potential alkali-silica reactions, and corrosive elements. Developing durable geopolymer formulations remains a sophisticated challenge.
- **Sourcing Quality RHA**: The procurement of high-grade RHA might be inconsistent due to geographical and seasonal factors. Ensuring a steady, quality supply is vital for the scalability of RHA-based geopolymer concrete, particularly in areas where RHA production is not established.
- **Balancing Costs**: Evaluating the economic viability of incorporating RHA into geopolymer concrete is essential. It involves comparing the financial aspects of geopolymer and traditional concrete, including raw material expenses, processing requirements, and the longevity of the final product.
- **Industry Adoption**: As geopolymer concrete is a newer entry into the building sector, its acceptance can be met with hesitancy from industry professionals and regulatory entities. To surmount this, an emphasis on education and the dissemination

of information regarding the advantages and efficacy of geopolymer concrete is imperative.

Properties of Geopolymer Concrete with Rice Husk Ash:

- **Compressive Strength**: A pivotal characteristic of geopolymer concrete incorporating rice husk ash (RHA) is its compressive strength. For M40 grade concrete, a benchmark strength of 40 MPa is mandatory. The study aims to identify the precise RHA substitution ratio that upholds the required compressive strength, ensuring the concrete's structural reliability.
- **Split Tensile Strength**: This parameter gauges the concrete's capacity to withstand tension. The research explores how RHA inclusion affects the split tensile strength of geopolymer concrete to confirm compliance with the standards for M40 grade concrete.
- **Flexural Strength**: This property reflects the concrete's resistance to bending forces, a vital factor for elements under bending stress. The flexural strength of geopolymer concrete with RHA is scrutinized within this study to validate its applicability for M40 grade structural uses.
- **Durability**: Longevity under various conditions is essential for geopolymer concrete with RHA. It should endure freeze-thaw cycles, chemical exposure, and wear. The study's durability tests ascertain whether this concrete variant can withstand environmental influences throughout its expected lifespan.
- **Water Absorption**: Indicative of concrete's porosity and its defense against water seepage, low water absorption rates are preferable to mitigate moisture-related damage. The research measures how well geopolymer concrete with RHA resists water absorption, ensuring enhanced moisture barrier qualities.
- **Chloride Permeability**: The intrusion of chloride ions can lead to the corrosion of internal steel reinforcements. Therefore, the research includes an assessment of RHA-infused geopolymer concrete's resistance to chloride penetration, a crucial attribute for structures in harsh environments.
- **Carbonation Resistance**: The study also examines how well this concrete variant stands up against carbonation—a process where CO2 compromises the concrete's alkalinity and structural integrity. Ensuring robust carbonation resistance is fundamental for the concrete's durability.
- **Microstructural Integrity**: Analyzing the microstructure of geopolymer concrete with RHA sheds light on the bonding and reaction processes within the material. Techniques such as SEM and XRD are leveraged to inspect the geopolymer matrix, pinpointing the presence of beneficial mineral phases and ensuring the concrete's performance aligns with M40 grade expectations.

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II. METHODOLOGY

Partial Replacement of Cement

Partial replacement of cement refers to the practice of substituting a portion of cement in concrete or mortar mixes with alternative materials. This approach is aimed at improving certain properties of the mixture or reducing environmental impact. There are several common materials used for partial replacement of cement:

- **Fly Ash:** Fly ash is a byproduct of coal combustion in power plants. It is commonly used as a partial replacement for cement in concrete. Fly ash improves workability, reduces heat generation during hydration, and enhances long-term strength and durability.

Figure 1: Fly Ash

- **Slag:** Ground granulated blast furnace slag (GGBFS) is a byproduct of iron production in blast furnaces. It can be used as a partial cement replacement to improve the workability, strength, and durability of concrete. Slag also reduces the heat of hydration and provides better resistance to chemical attack.

Figure 2: Slag

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- **Silica Fume:** Silica fume is a highly reactive pozzolanic material, which is a byproduct of silicon and ferrosilicon alloy production. When used as a partial replacement for cement, silica fume improves the strength, durability, and impermeability of concrete. It also enhances resistance to chloride ion penetration and sulfate attack.

Figure 3: Silica Fume

- **Rice Husk Ash:** Rice husk ash (RHA) is obtained from the combustion of rice husks. It contains high amounts of silica and can be used as a partial replacement for cement. RHA improves workability, reduces water demand, enhances the strength, and reduces the risk of alkali-silica reaction in concrete.

Figure 4: Rice Husk Ash

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- **Natural Pozzolans:** Natural pozzolans, such as volcanic ash, calcined clay, and certain types of shale, can be used as partial replacements for cement. These materials have pozzolanic properties, reacting with calcium hydroxide to form additional cementitious compounds, improving strength, and reducing permeability.

The partial replacement of cement with these alternative materials can have several benefits, including improved workability, increased long-term strength, reduced environmental impact, and lower costs. However, it's essential to consider the specific characteristics of the alternative material, the desired properties of the mixture, and any potential interactions or limitations when determining the appropriate replacement ratio.

Rice Husk Ash as a Pozzolan for Geopolymer Concrete:

Rice Husk Ash (RHA) serves as a pozzolanic substance, enhancing the synthesis of geopolymer concrete—a sustainable alternative to traditional concrete utilizing geopolymers as binders instead of Portland cement. This eco-friendly concrete boasts lower CO2 emissions, superior longevity, and improved resistance to chemicals.

Here's a guide to crafting geopolymer concrete with RHA:

- **Ingredients**: The essential materials include rice husk ash, alkaline solutions (often a mix of sodium hydroxide and sodium silicate), aggregate materials, and water.
- **Formulation**: For an M40 grade concrete, a specific formulation that determines the correct ratios of RHA, alkaline solutions, and aggregates is crucial. This step may require a series of lab tests for fine-tuning.
- **Blending**: Initially, the dry ingredients like RHA and aggregates are mixed. Subsequently, alkaline solutions are incorporated gradually, ensuring a consistent mix.
- **Molding**: The mix is then transferred into molds or formworks, with thorough compaction to eliminate air pockets for optimal solidity.
- **Curing**: The strength of geopolymer concrete develops during the curing phase, which might vary based on the geopolymer composition but generally requires maintaining certain temperature and humidity levels over a period.
- **Evaluation**: Post-curing, tests for compressive strength, flexural resilience, density, and more are conducted to confirm if the M40 grade specifications are met.

The specific process for RHA-based geopolymer concrete may need adjustments according to the unique properties of the RHA used, the alkaline activator's nature and concentration, and other materials involved. Expert advice from concrete technologists is advised for accurate mix design and production technique implementation.

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Black Rice Husk Ash (BRHA)

BRHA is derived from burning the husks of black rice, which is rich in anthocyanins, giving it a distinctive black or purple hue. The ash inherits a dark color and contains minerals and nutrients from the original husks.

As an agricultural by-product, BRHA is emerging as a valuable soil enhancer, providing vital nutrients like potassium, silica, calcium, magnesium, and other trace elements. Its high silica content is particularly beneficial for plant health and soil texture improvement.

Studies on BRHA's application in soil have shown promising results: it can improve nutrient absorption, water retention, soil fertility, and decrease soil acidity. Its application may also bolster plant growth, root development, and yield.

Table 1: Chemical Components

Chemical Component	**Approximate Composition Range**
Silica (SiO_2)	85-95%
Carbon (C)	1-7%
Potassium (K_2O)	1-3%
Sodium (Na_2O)	0.5-2%
Calcium (CaO)	0.5-2%
Trace Elements	Varies depending on source

III. RESULTS & DISCUSSION

Material Collection and Preparation:

Obtain the required quantities of cement, rice husk ash, fine aggregate (sand), coarse aggregate (gravel), and water. Collect representative samples of rice husk ash and perform preliminary tests to determine its chemical composition and physical properties. Pre-treat the rice husk ash, if necessary, to remove impurities or unwanted materials. Prepare the geopolymer binder solution by activating the rice husk ash with an alkaline activator, such as sodium hydroxide (NaOH) or potassium hydroxide (KOH).

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Figure 5: Preparation

Mix Design:

Conduct a mix design process to determine the proportions of cement, rice husk ash, fine aggregate, and coarse aggregate to achieve the desired M40 grade of concrete. Consider the target compressive strength, workability requirements, and other specific project constraints while designing the mix.

Mixing Procedure:

Dry mix the cement, rice husk ash, fine aggregate, and coarse aggregate in the required proportions. Gradually add the geopolymer binder solution to the dry mix while continuously mixing to ensure proper dispersion and uniformity. Adjust the water content as needed to achieve the desired workability of the concrete mix.

Casting and Curing:

Pour the freshly mixed geopolymer concrete into molds or formwork, ensuring proper compaction to eliminate voids and air pockets. Cover the molds to prevent moisture loss and allow the concrete to cure under controlled conditions. Maintain the curing temperature and humidity as per the geopolymer concrete specifications to promote optimal strength development and durability.

Figure 6: Casting and Curing

Testing and Evaluation:

After the specified curing period, demold the geopolymer concrete specimens and prepare them for testing. Conduct various tests, including compressive strength, flexural strength, and durability tests, according to relevant standards and procedures. Record and analyze the test results to evaluate the performance of the geopolymer concrete with varying percentages of rice husk ash replacement.

Figure 7: Compression testing machine

Compressive strength results

The compressive strength results of different mixes are given by fig. In the present investigation compressive strength of concrete produced by replacing Cement by Rice Husk Ash without addition of Super plasticizer (0%, 10%, 20%, 30%, 40%and50%) adding.

Table 2: The compressive strength results of different mixes

Vol of Cement	Vol of RHA	Cube Compressive Strength that 7 Days (N/mm^2)		
		Cube 1	Cube 2	Cube 3
100%	0%	25.76	25.25	26.02
90%	10%	26.97	27.15	26.76
80%	20%	28.73	28.61	28.35
70%	30%	28.95	29.07	29.15

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60%	40%	29.45	29.34	29.66
50%	50%	23.86	24.06	23.67

Table 3: Compressive strength

S. No	NaOH concentration	Mix	Average compressive strength (MPa)			
			3 days	7 days	28 days	90 days
1	5 M	0%	56.2	60.5	62.7	65.5
		10%	58.9	61.4	62.9	66.1
		20%	39.9	41.4	43.3	45.4
		30%	17.8	18.6	19.1	21
2	8 M	0%	60.9	66.5	69.3	72.5
		10%	62.3	67.6	70.7	73.2
		20%	44.7	46.3	51.5	54.1
		30%	19.2	20.5	22.5	24.1
3	11 M	0%	67.1	72.1	74.3	77.4
		10%	69.1	75.1	76.8	80
		20%	49.5	54.5	56.6	59.5
		30%	21.4	22.8	23.4	25.7

Table 4: Splitting Tensile and Flexural Strength Tests

S. No	Mix	Split tensile			Flexural		
		3 days	7 days	28 days	3 days	7 days	28 days
1	0%	6.2	6.4	6.7	5.1	5.7	6.1
2	10%	6.5	6.7	6.9	5.7	6.3	7.1
3	20%	3.7	3.9	4.3	3.2	3.6	4.1
4	30%	0.8	0.9	1.1	0.9	1	1.3

Table 5: Durability Test

S. No	Mix	Weight loss (%)			Strength loss (%)		
		30 days	60 days	90 days	30 days	60 days	90 days
1	0%	0.25	3.45	6.1	3.3	10.25	15.2
2	10%	0.1	2.85	4.9	2.9	9.6	13.4
3	20%	0.1	3.1	5.2	3.2	10	13.9
4	30%	0.4	5.6	10.8	9.8	24	39.5

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ISSN PRINT 2319 1775 Online 2320 787
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GRAPHICAL REPRESENTATION OF TEST RESULTS

The variation of compressive strength with molar concentration of NaOH is shown in fig 8. It shows that an increase in the compressive strength takes place as the molar concentration of NaOH solution is increased. Because the rate of leaching action of NaOH solution is increased due to the higher molar concentration of NaOH solution. The increase in strength from 8M to 12M is approximately 27% and 8M to 14M is 36%.

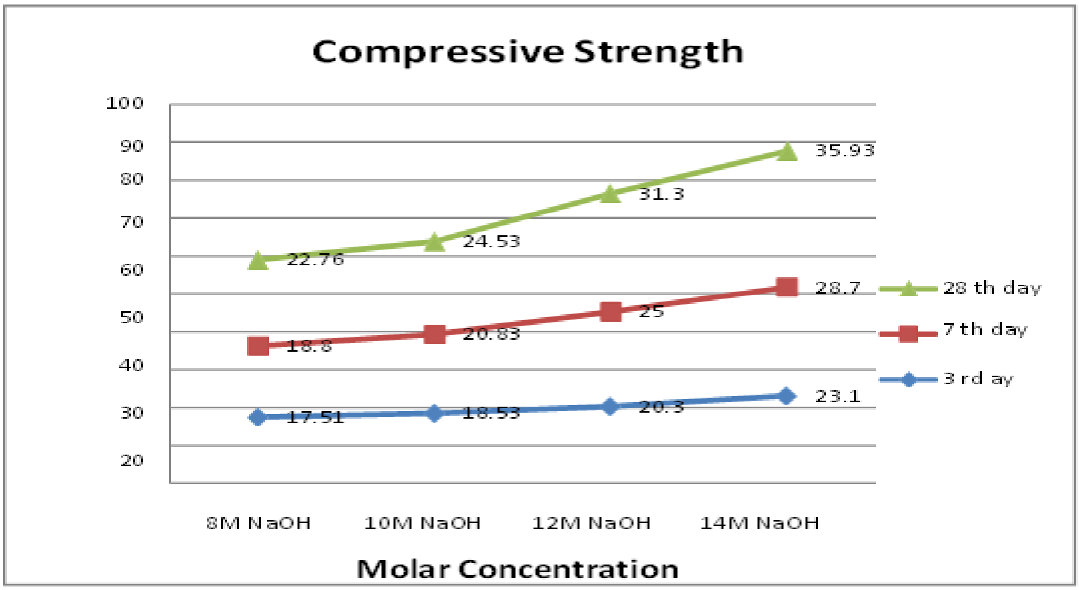

Figure 8: Variation of compressive strength with molar concentration of NaOH

The variation in total charge passed through cylindrical specimen is shown in Figure 8. The graph shows that the decrease in total charge passed through the cylindrical specimen of 12M concentration of NaOH solution if the age increases RCPT value decreasing. Charge passed in coulomb denotes the ingress of chloride ions through the concrete specimen.

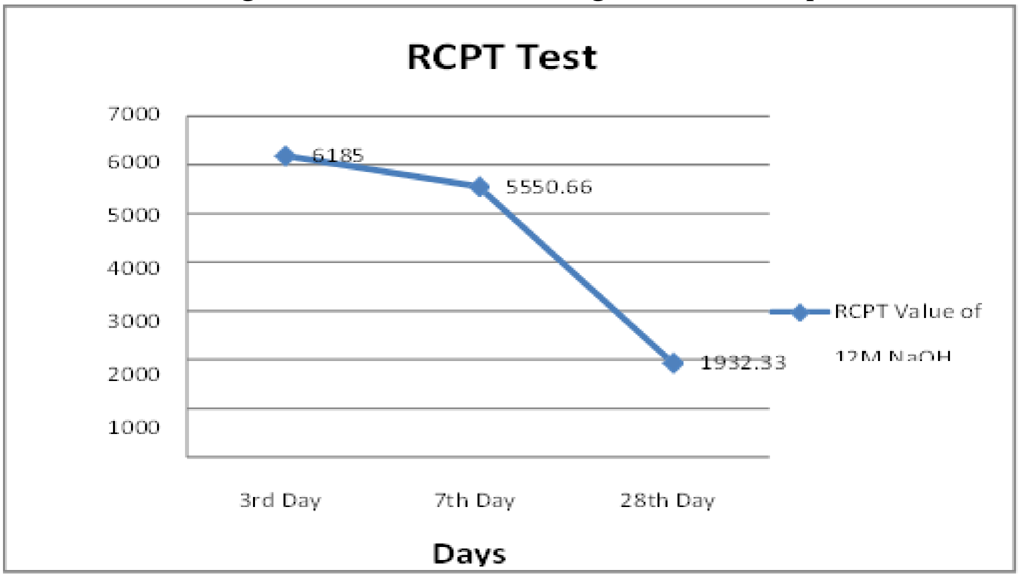

Figure 9: Variation in total charge passed through cylindrical specimen.

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IV. CONCLUSION

This research explores the impact of substituting ordinary cement with different ratios of rice husk ash (RHA) (ranging from 0% to 50%) in the production of M-40 grade concrete. The study's results reveal that the optimal replacement level of cement with RHA is 8% by weight, which not only enhances the concrete's physical and mechanical attributes but also decreases the cost of construction by up to 30%. This finding is particularly beneficial in regions where cement is scarce or transportation is a challenge. Additionally, incorporating RHA as a replacement material offers environmental advantages by reducing the burden of waste disposal and lessening the consequent pollution. The research pays special attention to the compressive strength of concrete, which shows a marked increase with the inclusion of RHA. Durability assessments further confirm that the concrete maintains its integrity across various levels of RHA incorporation.

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