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Examining Fresh Properties of Ternary Blended Cement Concrete Containing Rice Husk Ash and Metakaolin for Sustainable Construction Practices in Nigeria

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Abstract

Cement production in Nigeria is substantially contributing to its Gross Domestic Product. However, its production is adversely impacting the environment due to excessive exploration. This study examined the effect of combining Rice Husk Ash (RHA) and Metakaolin (MK) as partial replacement for cement on fresh properties of ternary blended concrete as a sustainable material. Therefore, a mixed-method experimental research approach involving laboratory experiment was adopted for the study. Concrete and paste samples (1:1.6:2) were prepared with binary (RHA or MK) individually and ternary (RHA + MK) replacement levels ranging from 10% to 30% and cured at 7, 28 and 90 days. Fresh properties including consistency, setting time, and workability were evaluated in accordance with relevant international standards. Findings indicate that a 15% ternary blend (RHA + MK) accelerated the setting time by 44 minutes relative to a 15% RHA binary blend, while exhibiting a 45-minute delay compared to a 15% MK binary blend.

At 20% replacement level, the ternary blend increased water demand by 1.5% compared to MK binary paste but reduced it by 3.5% when compared with 20% RHA binary paste. All ternary blends up to 30% replacement satisfied standard limits for initial and final setting times. Although ternary mixes required more water than MK binary blends, their water demand was lower than that of RHA binary mixes. The study concludes that combining RHA and MK in ternary cement systems enhances the fresh performance of concrete and provides a sustainable alternative for producing durable cementitious materials suitable for Nigeria's construction industry.

Keywords: Construction Industry, Fresh Concrete Properties, Rice Husk Ash, Metakaolin, Setting Time, Sustainability, Ternary Blended Cement

Introduction

The construction sector in Nigeria constitutes a major driver of national economic development and serves as a benchmark for assessing governmental performance in infrastructure delivery in general (Shehu & Shehu, 2022; Saidu et al. 2025; Umar et al. 2025). However, the production of construction materials is energy-intensive and contributes significantly to environmental degradation through greenhouse gas emissions, land degradation, depletion of natural resources, and alterations in land use patterns (Bashir, Dukku & Shehu, 2021). Cement manufacturing represents one of the most prominent industrial activities in Nigeria, making a substantial contribution to the country's GDP. The nation hosts several major cement producers, including Dangote, BUA, Ashaka, Sokoto, Mangal, and Ibeto Cement. Globally, cement production accounts for approximately 8% of total carbon dioxide (CO_2) emissions (Le, 2015; Bashir, Dukku, Shehu & Biri, 2021; Salama, Raafat, ElDamshiry et al. 2025). Basically, every activity involved in extraction, processing and delivery of construction materials often results in energy consumption, pollution and waste among others. The construction industry is often described as the "40% industry" due to its consumption of about 40% of global resources and its contribution to nearly 40% of total waste and greenhouse gas emissions (Bashir, Dukku & Shehu, 2021; Plessis, 2002). Therefore, due to the environmental and public health concerns associated with cement production, there is a growing need to partially replace cement with more sustainable, locally available materials. Nigeria's northern region, which constitutes approximately 70% of the country's landmass, is a major hub for rice production (National Population Commission [NPC], 2010; Shehu et al. 2025; Shehu, 2025).

Global paddy rice production in 2010 was estimated at 678 million tonnes, generating approximately 149 million tonnes of rice husk and about 37 million tonnes of rice husk ash (RHA) (FAO, 2009; Alsaed & Al Mufti, 2024). However, large quantities of RHA are often discarded indiscriminately, leading to environmental pollution and soil degradation (Alsaed & Al Mufti, 2024).

Considering the variability in material properties, experimental approaches and uniqueness of built environments across the globe, continuous investigation is this area of construction technology is essential.

Therefore, this study evaluates fresh properties of concrete focusing on consistency, setting time, and workability performance of ternary blended cement concrete incorporating RHA and MK for sustainable practices in the Nigerian construction industry.

An Overview

The utilization of RHA as a supplementary cementitious material (SCM) could offer an environmentally sustainable solution. Similarly, metakaolin (MK), white in colour, amorphous, a highly reactive Aluminium Silicate pozzolanic material obtained from calcined kaolinite, has been widely reported to enhance the mechanical and durability properties of concrete (Salama et al. 2025; Hasan, Khatun, Mazumder et al. 2025; Shehu, Jemal, Malami et al. 2022).

RHA, a by-product of rice milling, is rich in amorphous silica and highly pozzolanic when properly processed (El-Dakroury & Gasser, 2008). RHA has lower specific gravity than Ordinary Portland Cement (OPC) and a significantly higher fineness than OPC, which is essential for producing a denser and more durable concrete structure (Wagan, Memon, Memon et al. 2022). MK a dehydroxylated form of kaolinite, improves microstructures and mechanical performance due to its fine particle size and high reactivity (Brooks & Johari, 2001). MK is a high-quality pozzolanic material, is nowadays widely used as part of mineral admixtures for increase in performance and economy of concrete as partial replacement for OPC. Kaolin clay is the raw material used in producing Metakaolin at temperature 650^0C to 850^0C. While numerous studies have examined binary blends of cement with either RHA or MK, limited research has focused on their combined application in ternary systems, particularly in relation to fresh concrete behaviour, for instance, Hasan et al., (2025), Keshta et al., (2025), Youssf et al., (2025), Alsaed and Al Mufti (2024), Elkerany et al., (2023), and Wagan et al., (2022). It is noteworthy that most these studies were conducted overseas. Only few including, Shehu et al., (2022) conducted research in Nigeria on fresh concrete focusing on its rapid hydration in hot weather climate using Gum Arabic powder as a setting time retarder admixture.

MATERIALS AND METHODS

According to Shehu (2021), Shehu (2024), and Shehu and Shehu (2023) before choosing a design, researchers should consider the purpose, objectives, hypotheses and or questions of the study. This study evaluates fresh properties of ternary blended cement concrete containing rice husk ash and metakaolin for sustainable construction practices in Nigeria. Therefore, a mixed-method research design using experiment and observation was employed to obtained data for this study. Figure 1 depicts the summary of the research methodology adapted for this study. Basically, RHA, and MK cement additive concrete were tested and compared in terms of consistency, setting time, and workability performance of the ternary blends.

Materials:

The materials used for the study include: Portland Limestone Cement (PLC), Rice Husk Ash (RHA), Metakaolin (MK), superplasticizer (Complast 430), crushed granite as coarse aggregate, river sand used as fine aggregate and potable water. All materials complied with relevant international standards for concrete production.

A. Binders:
   - Portland Limestone Cement (PLC): The PLC used in this research work was Dangote brand of cement, 417 kg/m^3 conforming to BS EN 197-1 (2000).
   - Rice Husk Ash (RHA): Produced by controlled combustion of rice husk at 650 °C for 48 hours, followed by grinding and sieving in accordance with ASTM C618 (2005).
   - Metakaolin: Obtained from calcined kaolin sourced from Kankara LGA, Katsina State, Nigeria, heated at 750 °C for 2 hours to produce amorphous MK, conforming to ASTM C618 (2005).

B. Superplasticizer (Admixture):
   - Complast 430 superplasticizer (ASTM C494 Type D & G) was used to enhance workability while minimizing water demand (Shehu et al. 2022).

C. Aggregates:
   - Fine Aggregate: Natural River sand (≤5mm) 778kg/m^3 conforming to BS EN 882: 109 (1992) requirements was used.
   - Coarse Aggregate: Crushed granite with a maximum size of 20 mm, 960kg/m^3 meeting BS EN 812 (1992), BS EN 882 (1990) and BS EN 933 (1997) requirements respectively.

D. Water:
   - Clean potable tap water 200kg/m^3 was used for all mixes, which conformed to BS EN 1008 (2002), and (Shehu et al. 2022).

E. Preparation of Specimens:
   - Concrete of grade 50N/mm2 was designed using the Building Research Establishment (BRE) method, resulting in a mix proportion of 1:1.6:2. The constituents of the concretes are shown in Table 1. Cement up to 30% was replaced with RHA, MK or RHA and MK to produce different binary and ternary specimens. Binary specimens are the ones with either RHA or MK replacing cement, while the ternary specimens are those with MK and RHA replacing cement. For the fresh properties, five (5) samples were used for each test and average results was recorded, while for the Harden properties after mixing, the specimens were cast in cubes moulds (100mm x 100mm x 100mm) and cylindrical moulds (100 mm ø x 200 mm). The specimens were then demoulded after 24 hours of casting and then water cured for 7, 28 and 90 days before testing [15]. Five (5) samples were used for each test and average results was recorded. The Mix constituents of the concrete specimens are presented in Table 2.

Table 1: Concrete binder proportion

Specimen		PLC (%)	RHA (%)	MK (%)
Control	100% PLC	100	0.0	0.0
	10%RHA	90.0	10.0	0.0
RHA Binary blend	15%RHA	85.0	15.0	0.0
	20%RHA	80.0	20.0	0.0
	25%RHA	75.0	25.0	0.0
	30%RHA	70.0	30.0	0.0
	10%MK	90.0	0.0	10.0
	15%MK	85.0	0.0	15.0
MK Binary blend	20%MK	80.0	0.0	20.0
	25%MK	75.0	0.0	25.0
	30%MK	70.0	0.0	30.0
	10%TNR	90.0	5.0	5.0
	15%TNR	85.0	7.5	7.5
PLC+RHA+MK Ternary Blend	20%TNR	80.0	10.0	10.0
	25%TNR	75.0	12.5	12.5
	30%TNR	70.0	15.0	15.0

Source: Author's Field Work

Table 2: Mix Constituents of Concrete Specimens in Kg/m^3

Sample	(PLC) Cement	MK	RHA	W/C	Water Content	F. A	C.A	SP (%)	Slump (mm)
Control (100% PLC)	467	0	0	0.45	210	747	934	0.002	55
10%MK	420	47	0	0.45	210	747	934	0.002	58
15%MK	397	70	0	0.45	210	747	934	0.005	54
20%MK	374	93	0	0.45	210	747	934	0.006	55
25%MK	350	112	0	0.45	210	747	934	0.007	59
30%MK	327	140	0	0.45	210	747	934	0.007	57
10%RHA	420	0	47	0.45	210	747	934	0.006	52
15%RHA	397	0	70	0.45	210	747	934	0.008	59
20%RHA	374	0	93	0.45	210	747	934	0.012	53
25%RHA	350	0	112	0.45	210	747	934	0.016	60
30%RHA	327	0	140	0.45	210	747	934	0.023	58
10%TNR	420	23.5	23.5	0.45	210	747	934	0.004	59
15%TNR	397	35	35	0.45	210	747	934	0.007	55
20%TNR	374	46.5	46.5	0.45	210	747	934	0.009	58
25%TNR	350	56	56	0.45	210	747	934	0.011	52
30%TNR	327	70	70	0.45	210	747	934	0.015	51

Source: Author's Field Work

Experimental Methods:

A. Preparation of Pozzolana at 10-30% Level:

- RHA: Burnt at a temperature of 650^{0}C for 48 hours, cool ground and sieved.
- MK: Calcined kaolin heated at 750^{o}C for 2 hours, cool ground and sieved.
- Pozzolana (RHA + MK) were prepared in three samples (mix) 10%, 15%, 20%, 25% and 30%

B. Test Conducted:

- Fineness: Sieve analysis in accordance with BS EN 882: 109 (1992) requirements.
- Specific gravity: Pycnometer method in accordance with ASTM-C127-88 (1993) standard requirements.
- Chemical composition: Determined by X-ray Fluorescence (XRF) analysis.
- Consistency and setting time: Measured using Vicat apparatus in line with ASTM, C403 / C403M - 16. (n.d.) and Shehu et al. 2022) standard requirement.
- Workability: Slump test was conducted in accordance with BS EN, 12350-2 (2000), and Shehu et al. 2022).

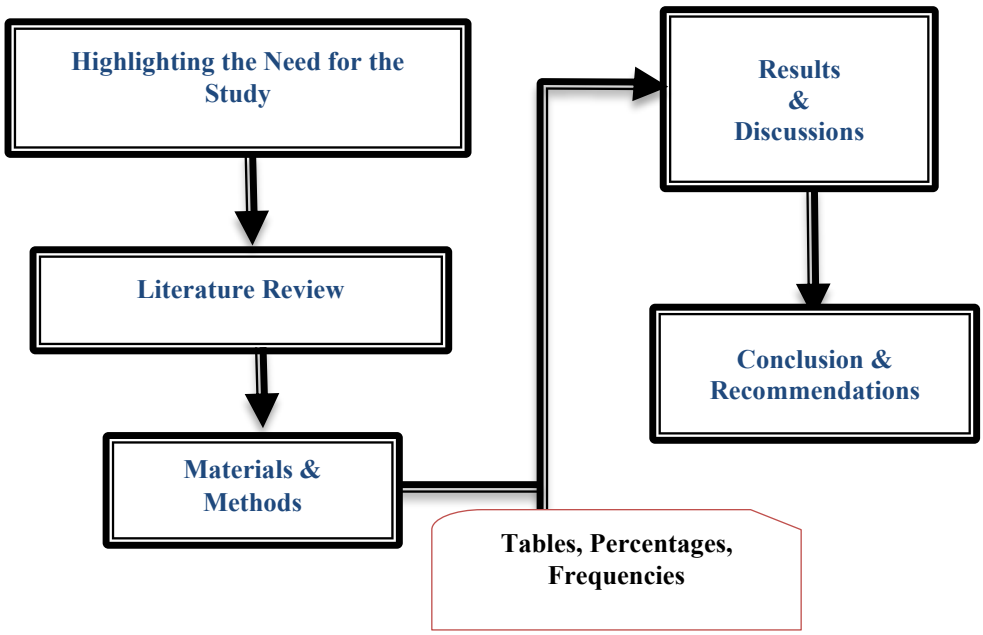


Figure 1: Research Methodology Flow Chart
Source: Adapted from Saidu et al. (2025), Umar et al. (2025)

RESULTS AND DISCUSSION

Table 3 shows the results of the chemical compositions. Findings indicate that both Rice Husk Ash (RHA) and Metakaolin (MK) satisfy ASTM C618 (2005) requirements for supplementary cementitious materials. The combined oxide contents (SiO_2 + Al_2O_3 + Fe_2O_3) were 72.23%

for RHA and 88.87% for MK, exceeding the 70% minimum threshold for pozzolanic classification. This indicates strong reactivity potential in cementitious systems.

Table 3: Chemical compositions

Oxide	RHA%	MK%	PLC%	ASTM C618 Requirement
SiO_2	66.99	57.13	20.55	-
Al_2O_3	0.48	17.77	5.07	-
Fe_2O_3	4.76	13.97	3.10	-
CaO	5.41	1.05	64.51	-
K_2O	8.58	4.71	0.73	-
LOI	3.60	6.20	1.58	RHA≤ 6%, MK ≤ 10%,
Σ (SiO_2 + Al_2O_3 + Fe_2O_3)	72.23	88.87	-	≥70

Table 4 shows the result of the physical properties of binders. Findings revealed that both materials demonstrated high fineness (RHA: 99%; MK: 93% passing 45 μm sieve) and strength activity indices above 75% (RHA: 88%; MK: 95%), confirming their suitability as cement replacements. The lower specific gravity of RHA (2.11) and MK (2.45) relative to PLC (3.15) suggests improved particle packing and potential microstructural refinement in blended systems.

Table 4: Physical properties of binders

Properties	RHA	MK	PLC	ASTM C 618 (2005) Requirements
Specific gravity	2.11	2.45	3.15	
Fineness (% passing 45μm sieve)	99.00	93.00	-	≥66
Strength activity index (%)	88.00	95.00	-	≥75.00%

Table 5 shows the results of the setting times of pastes of different mixes. Findings shows that all mixes complied with BS EN 196-1 (1995) standards for initial (≥45 min) and final setting times (≤600 min), except high RHA binary blends above 20%, which exhibited excessive retardation. The 15% ternary blend (7.5% RHA + 7.5% MK) accelerated setting by 44 minutes relative to 15% RHA binary mix but showed a 45-minute delay compared to 15% MK binary mix. This indicates a synergistic balance between the retarding effect of RHA and the comparatively reactive behaviour of MK.

Notably, ternary blends between 15-20% achieved optimal setting performance without exceeding standard limits, suggesting improved early hydration kinetics and controlled reaction rates.

Table 5: Setting times of pastes of different mixes

Mix Type	Binder proportions	Setting time (mins)		BS EN 196 (1995) requirements (Minutes)	
		Initial	Final	Initial	Final
Control	100% cement	118	185	≥45	
MK Binary	10% MK	159	190	≥45	≤ 600
	15 % MK	184	244		
	20%MK	225	265		
	25%MK	228	270		
	30%MK	230	276		
RHA Binary	10% RHA	212	287	≥45	≤ 600
	15 % RHA	273	393		
	20% RHA	275	607		
	25% RHA	300	625		
	30% RHA	325	687		
Ternary of MK & RHA	10% TNR	189	206	≥45	≤ 600
	15 % TNR	229	225		
	20% TNR	232	283		
	25% TNR	250	318		
	30% TNR	270	333		

Table 6 shows the results of the workability of the blends. Findings reveal that Slump values for all mixes ranged between 51–60 mm, indicating medium workability suitable for structural concrete applications. However, superplasticizer (SP) demand varied significantly: RHA binary blends: 2.88-10.59%; MK binary blends: 1.06-3.36%; and Ternary blends: 2.00–7.00%. The high SP requirement in RHA blends is attributed to its porous morphology and large specific surface area, which increases water absorption and internal friction. MK exhibited lower admixture demand due to finer particle dispersion and improved packing density. Ternary blends required lower SP dosages than RHA-only mixes, confirming that MK moderates the rheological limitations of RHA. This reduction has important practical implications for cost efficiency and mix stability.

Table 6: Workability and Admixture Demand

Mix type	Replacement (%)	SP Dosage (%)	Slump
100% cement	0	0.00-0.88	55
RHA Binary	10-30	2.88-10.59	52-60
MK Binary	10-30	1.06-3.36	54-59
Ternary (RHA+MK)	10-30	2.00-7.00	51-59

Table 7 shows the results for consistency of pastes. Findings indicate that Consistency values increased with higher replacement levels across all blends. RHA binary mixes recorded the highest water demand (up to 45%), exceeding acceptable limits at high replacement levels.

MK binary blends showed moderate increases (28–35%), while ternary blends ranged between 30.75–38.5%. Importantly, ternary blends up to 20% replacement remained within the ≤33% consistency threshold specified by BS EN 197-1 (2000). At 20% replacement, ternary paste increased water demand by only 1.5% compared to MK binary paste but reduced it by 3.5% compared to RHA binary paste. This confirms improved water efficiency in ternary systems relative to RHA-only mixes.

Table 7: Consistency and Water Demand

Mix type	Replacement (%)	Consistency (%)
100% cement	0	27.50
RHA Binary	10-30	32.75-45.00
MK Binary	10-30	28-35.00
Ternary (RHA+MK)	10-30	30.75-38.50

Discussion of Findings

The findings primarily show that ternary blending of RHA and MK produces complementary physicochemical interactions that enhance fresh concrete performance. Individually, RHA and MK exhibit distinct behaviours: RHA increases water demand and retards setting, while MK contributes to microstructural refinement but may moderately extend setting time at higher replacements.

When combined, the contrasting characteristics are moderated, resulting in balanced hydration behaviour and manageable rheological performance. The synergistic performance likely arises from improved particle packing, filler effects, and enhanced nucleation sites provided by MK, which compensate for the slower reactivity of RHA. Also, the findings of this study showed that, the Binary MK blends showed moderate extension of setting time with increasing replacement, attributable to dilution effects and slower early hydration relative to cement. In contrast, RHA binary blends demonstrated pronounced retardation, particularly beyond 20% replacement, due to high silica content and delayed pozzolanic reaction. While the Ternary blends exhibited a stabilizing interaction. The 15% ternary blend (7.5% RHA + 7.5% MK) accelerated setting by 44 minutes relative to 15% RHA binary mix but showed a 45-minute delay compared to 15% MK binary mix. Basically, RHA delays setting mainly due to its high Silica Oxide (SiO_2) contents, while MK accelerate setting due its Aluminate Oxide (Al_2O_3) content which reacts rapidly and enhances early hydration. These findings are consistent with previous studies (Shehu et al. 2022; Wagan et al. 2022; Le, Siewert & Ludwig, 2012; Ganesan, Rajagopal & Thangavel, 2008).

The 15-20% ternary replacement range appears to represent a threshold at which dilution effects, pozzolanic reactivity, and water demand are optimally balanced. Beyond 20%, excessive replacement may compromise early hydration kinetics and increase water demand beyond practical limits. The findings are in consonance with the experimental study on properties of self-compacting mortars with binary and ternary cementitious blends of fly ash (FA) and metakaolin that proved the combined use of the MK with FA in the ternary blends

provided remarkable reduction in the setting times of the mortars compared to when singly used (Güneyisi & Gesoğlu, 2008; Wagan, 2022; Hasan et al. 2025).

From a material science perspective, the interaction between silica-rich RHA and alumina-rich MK contributes to secondary calcium silicate hydrate (C–S–H) formation while maintaining workable consistency. Overall this result aligns with studies conducted by Alsaed and Al Mufti (2024), Muthadhi and Kothandaraman (2013), and Khan et al. (2012) respectively. This enhances early setting control without excessive retardation, which is critical in hot climates such as Nigeria where setting control affects placement and finishing operations (Shehu et al. 2022). The improved rheological performance of ternary blends compared to RHA-only systems is particularly significant. High superplasticizer demand not only increases cost but may also influence long-term durability. The reduction in SP dosage in ternary systems enhances both technical and economic feasibility. Overall, the findings validate the hypothesis that combining two supplementary cementitious materials can mitigate individual limitations and improve overall fresh concrete behaviour. The implication of the findings of the study are outline as follows:

- A sustainability base implication of this study is that partial replacement of cement with RHA and MK directly reduces clinker consumption, thereby lowering CO_2 emissions associated with cement production. Given that cement manufacturing contributes significantly to global greenhouse gas emissions, adopting ternary blended systems aligns with sustainable construction objectives. The utilization of RHA also addresses agricultural waste management challenges in Nigeria's rice-producing regions, promoting circular economy principles and environmental stewardship.
- The study establishes that ternary blends up to 20% replacement are technically viable for structural applications without compromising fresh properties. The 15% ternary blend offers optimal balance and may serve as a recommended benchmark for practical implementation. Concrete producers and construction firms can integrate RHA–MK ternary systems to enhance performance while maintaining compliance with international standards.
- Economically locally sourced RHA and MK reduce dependence on cement clinker and imported additives. Reduced superplasticizer demand in ternary systems further enhances economic efficiency. The adoption of such systems may reduce material costs while promoting local resource utilization.
- The findings support the development of national guidelines encouraging the use of supplementary cementitious materials in infrastructure projects. Policymakers may consider incentives for low-carbon construction materials.

CONCLUSION

This study was motivated due to increasing global concerns regarding climate change and the environmental impacts of cement production. This study evaluates the effect of fresh properties of ternary blended cement concrete incorporating both RHA and MK, focusing on consistency, setting time, and workability performance properties in the Nigerian construction industry. Based on the experimental findings, the study concludes that all concrete mixes

satisfied standard requirements for initial and final setting times. The 15% ternary blend (RHA + MK) demonstrated optimal setting performance by accelerating setting relative to RHA binary blends while slightly retarding it compared to MK binary blends. Although paste consistency increased with higher SCM content, ternary blends exhibited lower water demand than RHA-only mixes. Additionally, workability improved when RHA and MK were used together, resulting in reduced superplasticizer requirements. Ternary cement replacement levels of up to 20% were found to be suitable for practical applications where sustainability and fresh concrete performance are prioritized. Future studies should examine compressive strength development, durability indices, long-term hydration behaviour, and life-cycle assessment to establish comprehensive performance profiles. The study therefore recommends the adoption of RHA-MK ternary blended cement systems as a viable approach for producing sustainable and durable cementitious materials for the Nigerian construction sector of the economy.

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REFERENCES

Alsaed, M. M., & Al Mufti, R. L. (2024). The Effects of Rice Husk Ash as Bio-Cementitious Material in Concrete. Constr. Mater., 4, 629-639. https://doi.org/10.3390/constrmater4030034

ASTM, C403 / C403M - 16. (n.d.). Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance.

ASTM, C618 (2005). Specifications for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. American Society for Testing and Materials (ASTM International), 100, 19428-12959.

ASTM-C127-88 (1993). Standard Methods of Test for Specific Gravity, and Absorption of Coarse Aggregate.

Bashir, U. M., Dukku, S. J., & Shehu, S. (2021). Quantum of Building Demolished Debris in Urban Road Construction in Gombe City, Nigeria. African Journal of Environment and Natural Science Research. 4(3): 1-11. https://doi.org/10.52589/AJENSR-SAFEXNK8

Bashir, U. M., Dukku, S. J., Shehu, S., & Biri, H. B. (2021). Embodied Energy and Carbon from Building Demolished Debris Associated with Urban Road Construction in Gombe City, Nigeria. Borneo Journal of Science & Technology. 3(2): 33-38. DOI: http://doi.org/10.3570/bjost.2021.3.2-06

Brooks, J., & Johari, M. M. (2001). Effect of metakaolin on creep and shrinkage of concrete. Cement and Concrete Composites, 23(6), 495-502.

BS EN 812: 109 (1990). Method for Determination of Moisture Content of Aggregate. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

BS EN 882: 109 (1992). Aggregates from Natural Sources for Concrete. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

BS EN 933: 1 (1997). Determination of Particle Size Distribution – Sieving Method. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

BS EN, 1008 (2002). Mixing Water for Concrete. British Standards Institution: London, UK.

BS EN, 12350-2 (2000). Testing fresh concrete: slump test. London: British Standards Institution.

BS EN, 196-1 (1995). Methods on cements (Part 1): Determination of mechanical strength (Classification index P 15-471). Norme française (French standard).

BS EN, 197-1 (2000). Cement-Part 1: Composition, Specifications and Conformity Criteria for Common Cements. British Standards Institution.

El-Dakroury, A., & Gasser, M. (2008). Rice husk ash (RHA) as cement admixture for immobilization of liquid radioactive waste at different temperatures. Journal of nuclear materials, 381(3), 271-277.

Elkerany, A. M., Keshta, M. M., Elshikh, M. M. Y., Elshami, A. A., & Youssf, O. (2023). Characteristics of Sustainable Concrete Containing Metakaolin and Magnetized Water, *Buildings,* 13, 1430. https://doi.org/10.3390/buildings13061430

FAO (2009). Rice Market Monitor: Volume XII. FAO, Rome, Italy.

Ganesan, K., Rajagopal, K., & Thangavel, K. (2008). Rice husk ash blended cement: assessment of optimal level of replacement for strength and permeability properties of concrete. Construction and Building Materials, 22 (8), 1675-1683.

Güneyisi, E., & Gesoğlu, M. (2008). Properties of self-compacting mortars with binary and ternary cementitious blends of fly ash and metakaolin. Materials and Structures, 41(9), 1519-1531.

Hasan, K., Khatun, M. H., Mazumder, R., Jaya, R. P., & Yahaya, F. M. (2025). Performance of sustainable ternary blended concrete using rice husk ash and metakaolin as partial cement substitutes. Innovative Infrastructure Solutions. 10(11). DOI: 10.1007/s41062-025-02328-9

Keshta, M. M., Yousry Elshikh, M. M., & Elkerany, A. M. (2025). Performance of concrete containing different ratios of metakaolin and magnetized water. *Next Sustainability,* 6, 100107.

Khan, R., Jabbar, A., Ahmad, I., Khan, W., Khan, A. & Mirza, J. (2012). Reduction in environmental problems using rice-husk ash in concrete. Constr. Build. Mater. 30:360–365.

Le, H. T. (2015). Behaviour of Rice Husk Ash in Self-Compacting High-Performance Concrete (PHD Thesis). Institute for Building Materials Science, Bauhaus University Weimar, Germany.

Le, H., Siewert, K., & Ludwig, H. (2012). Synergistic Effects of Rice Husk Ash and Fly Ash on Properties of Self Compacting and High-Performance Concrete. Paper presented at the Proceedings of symposium on Ultra high-performance concrete and Nanotechnology for High performance construction materials, Kassel, Germany.

Muthadhi, A., & Kothandaraman, S. (2013). Experimental Investigations of Performance Characteristics of Rice Husk Ash–Blended Concrete. J. Mater. Civ. Eng. 25:1115–1118.

National Population Commission [NPC] (2010). Federal Republic of Nigeria: 2006 Population and Housing Census Priority Table Volume III.

Plessis, C. (2002). Sustainable Construction in Developing Countries, a Discussion Document, CSIR, Building and Construction Technology, Pretoria. South Africa.

Saidu, S., Waziri, A.Y., Ishaku, B., & Shehu, S. (2025). The Use of Social Media Tools for Effective Communication in Construction Project Delivery in Maiduguri Metropolis, Borno State. Bima Journal of Science and Technology. Vol. 8 (4B) 173-181. DOI: https://doi.org/10.56892/bima.v8i4B.1194

Salama, Z. A., Raafat, A., ElDamshiry, K. K., Micheal, A., & Moussa, R. R. (2025). A Green Concrete Mixture Using Rice Husk as Partially Cement Replacement. 16th International Conference on Civil and Architectural Engineering (ICCAE-16). IOP Conf. Series: Earth and Environmental Science 1530 (2025) 012006. doi:10.1088/1755-1315/1530/1/012006

Shehu, R., Jemal, M. A., Malami, S. I., & Muhammad, Z. U. (2022). Mitigating the Effect of Rapid Hydration of Fresh Concrete in Hot Weather Climate Using Gum Arabic Powder as A Setting Time Retarder Admixture. International Journal of Engineering Applied Sciences and Technology, 7 (5), 01-05

Shehu, S. (2021). Time Management Factors in Construction Project Delivery in Gombe State, Nigeria. Published M-Tech Thesis, Abubakar Tafawa Balewa University Bauchi, Nigeria.

Shehu, S. (2024). Perceptions of Stakeholders on the Impacts of Cost Management Success Factors on The Performance of Public Building Construction Projects in The Sahel Region: Evidence from Yobe State. Journal of Civil Engineering, Science and Technology, 15 (2). DOI: https://doi.org/10.33736/jcest.6791.2024

Shehu, S. (2025). Financing and Practices Inducing Compliance with Due Processes in the Procurement of Public Construction Projects in Nigeria's Local Government Area: A Case Study of Misau Council, Bauchi State. Proceedings of International Conference for Institute of Administration (ICIA) 6th – 9th July 2025 at Ahmadu Bello University Zaria, Nigeria.

Shehu, S., & Shehu, R. (2022). A Principle Framework for Determining Timely Completion of Building Projects in Public Tertiary Institutions in Bauchi and Gombe State, Nigeria. Borneo Journal of Sciences & Technology, 4(1): 80-90. DOI: https://doi.org/10.35370/bjost.2022.4.1-12

Shehu, S., & Shehu, R. (2023). Quality Performance Indicators of Building Construction Projects in Nigeria. Borneo Journal of Social Sciences and Humanities, 5(2), 24–42. https://doi.org/10.35370/bjssh.2023.5.2-03

Shehu, S., Ali, Z. A., Shehu, R., Aliyu, U., Muhammad, A., & Saidu, S. (2025). Practices Influencing Programme Abandonment, Time and Cost Overrun of Postgraduate Studies in The Built Environment in A Developing Economy. Proceedings of the Faculty of Management Science University of Maiduguri 2nd International Conference 11th -13th February, 2025, Maiduguri, Nigeria.

Umar, R. A., Zadawa, A. N., Shehu, S., Shehu, A. S & Yakubu, Y. (2025). Construction Procurement Processes in Public Tertiary Institutions: A Case Study of Gombe State, Nigeria. Dutse Journal of Pure and Applied Sciences. 11 (3b): 144-151. https://dx.doi.org/10.4314/dujopas.v11i3b.16

Wagan, I. H., Memon, A. H., Memon, N. A., Memon, F. T., & Lashari, M. H. (2022). Rice Husk Ash (RHA) Based Concrete: Workability and Compressive Strength with Different Dosages and Curing Ages. Journal of Applied Engineering Sciences, 12(25), pp.113-120. DOI: https://dx.doi.org/10.2478/jaes-2022-0016

Youssf, O., Eltawil, K. A., Elshikh, M. M. Y., & Keshta, M. M. (2025). Performance of High Strength Fiber Reinforced Mortar Made with Ceramic Powder, Metakaolin, and Magnetized Water. *Infrastructures*, 10, 124. https://doi.org/10.3390/infrastructures10050124