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Effect of Partial Replacement of Cement with Rice Husk Ash (RHA) on Concrete Performance Characteristics

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Abstract: *Cement is an essential constituent in concrete mixture that reacts with moisture to form cement paste, the binder of aggregates in concrete, and the sustainability and consumption over time period makes determination of alternative cementitous material a necessity. This study investigates the effects of partially replacing cement with rice husk ash (RHA) on concrete performance characteristics to reduce reliance on conventional cement as primary binding agent. Cement was replaced with RHA at 5%, 10%, 15%, and 20% by weight, while a 0% RHA mix served as the control. Tests on workability, compressive strength, and flexural strength were conducted to evaluate the performance of concrete containing varying RHA proportions. A mix ratio of 1:1.5:3 and a water-cement ratio of 0.5 were adopted, with samples subjected to both air and water curing at intervals of 3, 7, 14, 21, 28, and 42 days for compressive and split tensile strength assessments. The results showed that the inclusion of RHA enhanced compressive strength, with optimal performance observed at 15% replacement. However, split tensile strength decreased compared to the control mix. Regression model, σ = a + b*(RHA) + t^c) revealed further that RHA addition improves concrete workability and compressive strength up to a 15% replacement level. While RHA-enhanced concrete demonstrates favourable strength characteristics under compression, the reduced tensile strength suggests the low tensile strength behavior of concrete which commonly is associated with low bond strength during formation*

Keywords: *Cementitous, Concrete, Compressive-strength, Flexural-strength, Regression model,*

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1. INTRODUCTION

Concrete is a composite construction material formed by hydration of cement with water, binding fine and coarse aggregates into a unified, load-bearing material after the curing and hardening process (Amin and Mahmoud, 2017, & Abulaka (2012). Concrete performance depends extensively on mix design, which determines the ratio of components to achieve desired characteristics such as, strength and durability. Common parameters used in concrete mix proportioning include, water/cement ratio, aggregate quality, and desired fresh and hardened properties. Curing plays a critical role in transformation from fresh to hardened state and enhancing stability, strength, and durability by ensuring appropriate moisture and temperature conditions during the process (Afolabi et al, 2021).In pursuit of sustainability, researchers are exploring the use of industrial and agricultural waste materials as partial replacements for cement. One such material is rice husk Aash (RHA), a by-product of rice milling (Adamu and Umar, 2015). RHA has pozzolanic properties, meaning it can chemically react with calcium hydroxide to form compounds that improve concrete strength and durability. Studies show that incorporating RHA enhances properties such as workability, strength, and sustainability, though results vary based on usage levels and material characteristics. Increasing demand for sustainable construction materials has propelled research into the partial replacement of Ordinary Portland Cement (OPC) with pozzolanic materials (Abalaka, 2012 & Adamu and Gambo (2017). Rice Husk Ash (RHA), a by-product of rice milling, has produced significant attention due to its high silica content and pozzolanic reactivity (Chandrasekhar, 2003).This study explores the mechanical performance and workability of concrete with RHA replacing OPC at varying percentages. While RHA is known to improve long-term strength and reduce permeability due to its fine particle size and high specific surface area (Chao and Zhang, 2011), it also tends to decrease workability due to increased water demand. Rice Husk Ash (RHA) is widely recognized for its pozzolanic properties, primarily due to its high amorphous silica content. When processed correctly—particularly when combusted below 700°C—it can react with calcium hydroxide in cementitious systems to form additional calcium silicate hydrate (C-S-H), which contributes to strength and durability.

Bediako et al. (2020) studied the effect of co-firing clay and rice husk, with RHA content varying from 1.0% to 2.0%, calcined at 800°C. They found that the optimal mix (2.0% RHA) achieved the highest pozzolanic strength activity index (PSAI) when used at 30 wt% replacement. Advanced analyses using MAS NMR revealed enhanced calcium aluminosilicate phases and mono-sulphate formations, leading to improved strength and dimensional stability. Rashid (2016) evaluated cement mortar incorporating RHA at 10%, 15%, 20%, and 30% replacement levels. His results indicated strength improvement up to 90 days, especially at 15–20% replacements. However, initial setting time increased with RHA, though final setting was somewhat accelerated at higher contents—highlighting the dual role of RHA in both strength development and hydration dynamics. Similarly, Hasan et al. (2016) found that compressive strength peaked at 10% RHA replacement. Using a constant water-cement ratio of 0.485, they observed that early-age strength increased with curing age but decreased with higher RHA content beyond 10–15%, largely due to dilution of cement content.RHA is generated from the combustion of rice husks, which contain opaline silica and lignin. The resulting ash has a high surface area (Blaine number ~3600), often finer than cement (2800–3000), enhancing its reactivity and particle-packing ability. The controlled burning of husks below 700°C is essential to retain amorphous silica. Francisco et al. (2019) illustrated this with chemical analyses showing high SiO_2 content and negligible unburnt carbon—key to effective pozzolanic performance. When used in small amounts (2–3% of cement mass), Ephrain et al. (2012) demonstrated that while RHA-enhanced concrete remains workable (slump >100mm), and also requires careful water adjustment. Though the increase in water-demand does not significantly affect concrete compressive strength (between 33 N/mm2 to 38.4 N/mm2) at 28 days. In a microstructural study, Prasanphan et al. (2010) used scanning electron microscopy (SEM) and thermogravimetric analysis (TGA/DTA) to explore the internal structure of OPC pastes with 5% and 25% RHA. They found that the 5% RHA paste achieved higher strength than plain OPC after 7 days due to enhanced ettringite needle growth. However, 25% RHA consistently underperformed compared to the control, suggesting a trade-off between pozzolanic benefit and cement dilution at higher replacements. Objective of this study, was to evaluate the compressive strength and workability characteristics of RHA-blended concrete and identify an optimal replacement level that balances environmental benefits with practical performance. Also, experimental data from laboratory tests were further processed using statistical techniques such as regression analysis, which describes the relationship between dependent and independent variables (Unamba et al, 2021). Multiple regression models allow for predicting outcomes like compressive strength based on various influencing factors, supporting more informed and scientific decision-making in concrete technology.

II. MATERIALS AND METHODS

The methodology encompasses materials selection, mix proportioning, sample preparation, curing procedures, and testing protocols including relevant standards. The research employs an experimental design to compare the performance of concrete mixtures with varying percentages of RHA. The study involves producing concrete cubes and cylinders, with 0% (control), 5%, 10%, 15%, and 20% RHA as partial replacement of cement by weight. The properties of fresh and hardened concrete were assessed through standardized tests.

2.1 Materials

Followings are concrete constituent materials used for the study

Cement: Portland limestone cement (PLC) according to ASTM C150 specifications

Rice Husk Ash (RHA): RHA used to partially replaced cement as binder of aggregates in concrete, was obtained through controlled burning of rice husk and sieved through a 75 µm sieve to ensure fineness.

Fine Aggregate: Clean, river sand with a fineness modulus conforming to ASTM C33.

Coarse Aggregate: Crushed granite with a maximum size of 20 mm.

Water: Potable water free from impurities and suitable for concrete mixing and curing.

2.1.1: The Concrete constituents were proportioned and mixed using a mix ratio of 1 : 1½ :3 (cement : sand : coarse aggregate) by weight with a constant water-cement ratio of 0.5. The RHA replaced cement at 5%, 10%, 15%, and 20% by weight. The control mix (0% RHA) served as the baseline for comparison.

2.2 Casting and Testing

Concrete was mixed mechanically with concrete mixer, and specimens were cast in standard cubes (150 mm × 150 mm × 150 mm), and cylinder moulds (150mm dia. x 300mm). After 24 hours of casting, the specimens were demolded and cured in air and water at ambient temperature for 3, 7, 14, 21, 28, and 42 days.

Testing Procedures:

The following tests were conducted according to ASTM/BS standards:

Workability:

Slump test (ASTM C143) to assess fresh concrete workability.

Compressive Strength:

Cube specimens tested at 3, 7, 14, 21, 28, and 42 days (ASTM C39).

Split Tensile Strength:

Cylinder specimens tested at 3, 7, 14, 21, 28, and 42 days 28 days (ASTM C496).

2.2 Regression Model and Analysis

The Laboratory Results were further analyzed to established a relationship between time (after casting) and concrete strength, using regression model

$$\sigma = a + b*(RHA) + t^{c}$$

where RHA is percentage replacement of cement, t = duration of curing in days, and a, b and are regression parameters. Regression model provides functional expression that describes one or more independent variables and a response, or dependent variable and can be used to predict the compressive strength with respect to % level of RHA and curing period

III. RESULTS AND DISCUSSION

Results of laboratory experiments and statistical analysis were enumerated and discussed to determine the conclusion. The laboratory tests were implemented according to BS standard procedures, including test method for constituents materials and concrete properties.

3.1. Preliminary Tests; Sieve Analysis of Fine Aggregate (Sand), Conducted per BS standards. Fine aggregate mostly passed through a 0.60 mm sieve. Cu = 4.23, Cc = 0.993, *Poorly graded* sand. Sieve Analysis of Coarse Aggregate (Granite), Well-graded with Cu = 8.82, Cc = 1.02. Mostly retained on 5 mm sieve and Fineness Modulus = 2.08.

3.2. Concrete Slump Test

Concrete workability improved with increasing RHA (Rice Husk Ash). Slump ranged from 10 mm (0% RHA) to 30 mm (20% RHA), the results were within specified limits for medium workability concrete

3.3. Compressive Strength Test

Results of the compressive strength carried out with different levels of RHA replacements are shown in Table 3.1 and 3.2 below for both Air and Water cured samples.

3.3.1 Air Cured Concrete Cubes

Table 3.1: Laboratory and Regression model Compressive Strength Results for Air-cured

Curing Days	**0% Lab**	**0% Model**	**5% Lab**	**5% Model**	**10% Lab**	**10% Model**	**15% Lab**	**15% Model**	**20% Lab**	**20% Model**
3 days	13.43	17.05	11.08	16.65	11.45	16.72	11.42	16.71	10.55	16.56
7 days	17.04	19.78	13.27	19.53	13.27	19.14	12.31	18.98	11.26	18.80
14 days	23.22	23.93	19.95	23.48	19.95	23.28	19.20	23.26	19.18	23.25
21 days	27.68	27.44	22.53	26.64	22.53	26.57	20.58	26.24	22.22	26.52
28 days	27.57	29.96	23.22	29.22	23.22	29.22	22.02	29.02	22.40	29.08
42 days	29.70	34.99	23.15	33.98	23.15	33.89	27.92	34.69	29.45	34.95

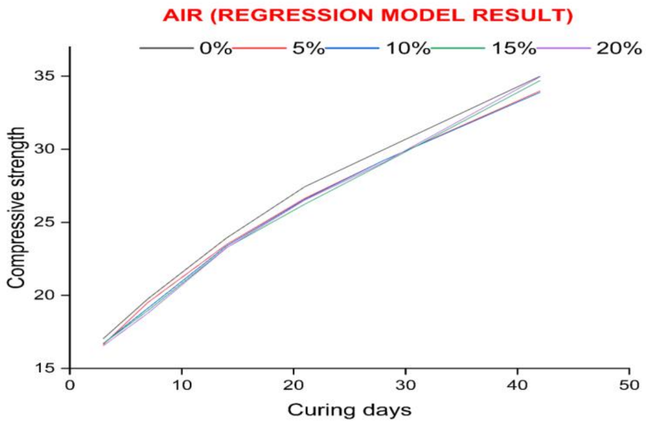

Fig 3.1: Graph of Curing Days Against Compressive Strength for Air-Cured Cubes

Table 3.1 and Fig. 3.1 are the results of cubes cured in air, which show that, compressive strength decreased with higher RHA levels, possibly due to w/c ratio and the curing methods could not provide adequate bond energy for the cement-paste/aggregate interface. The peak strength was observed around 28days (27.57 N/mm^2) and 42 days (29 70 N/mm^2) which compares adequately with the regression model values. Also, the rate of strength gain after 28 days (75% concrete overall strength) with other loading parameters, can be used in the prediction of future concrete compressive strength

3.3.2 Water-Cured Concrete Cubes

Table 3.2: Laboratory and Regression model Compressive Strength Results for Water-cured

CUBE TEST (WATER CURED)										
Model equation, σ = 12.461-0.169*(Rha) + 0.766**c Rha is % replacement level, t is curing period, and a, b, c are regression parameters										
Curing	0%	0%	5%	5%	10%	10%	15%	15%	20%	20%
Days	**Lab N/mm^2**	**Model N/mm^2**	**Lab N/mm^2**	**Model N/mm^2**	**Lab N/mm^2**	**Model N/mm^2**	**Lab N/mm^2**	**Model N/mm^2**	**Lab N/mm^2**	**Model N/mm^2**
3 days	14.61	15.46	13.41	15.62	12.98	15.68	13.15	15.65	12	15.8
7 days	19.81	17.31	18.50	17.53	17.6	17.65	17.01	17.73	15.47	17.93
14 days	25.42	20.61	24.48	20.74	28.65	20.19	24.07	20.79	22.4	21.01
21 days	29.57	23.72	28.37	23.88	30.07	23.66	28.32	23.89	27.02	24.05
28 days	31.35	26.94	30.34	27.07	33.01	26.73	31.59	26.91	30.1	27.1

42 days	35.08	32.97	34.52	33.04	34.52	33.04	32.36	33.32	31.23	33.47
Note Lab = Laboratory compressive test result Model = Regression model results										

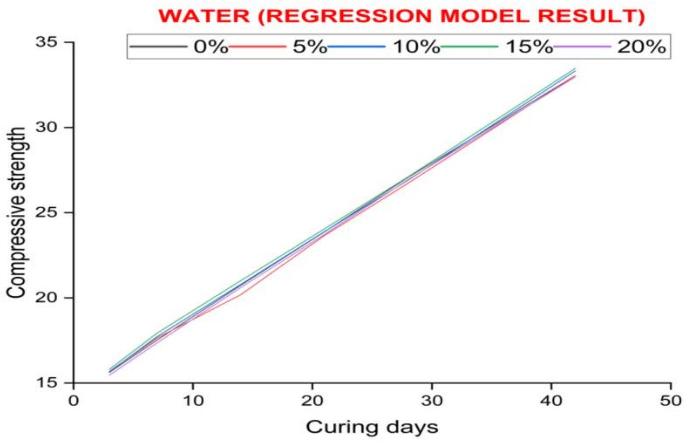

Fig 3.2: Graph of Curing Days Against Compressive Strength for Water-Cured Cubes

Fig 3.2 and table 3.2, are compressive strength of cubes cured in water, and show that the compressive strength increased with RHA, with maximum at 15% replacement level. Maximum compressive strength at 28 days (31.35 N/mm^2) and 42 days, 35.08 N/mm^2 (0% RHA).

3. 4 . Split Tensile Strength Test Results

3.4.1.Air-Cured Cylinders:

Tables 3.3 and 3.4 show the results of the compressive strength carried out with different levels of RHA replacements for the split tensile test for the air—and water-cured specimens.

Table 3.3: Laboratory and Regression Model Tensile strength of Air-cured Concrete Cylinder

SPLIT TENSILE TEST (AIR CURED)										
Model equation, σ = 2.344-0.062*(Rha) + 1.003**c Rha is % replacement level, t is curing period, and a, b, c are regression parameters										
	0%	0%	5%	5%	10%	10%	15%	15%	20%	20%
	Lab	**Model**	**Lab**	**Model**	**Lab**	**Model**	**Lab**	**Model**	**Lab**	**Model**
3 days	1.14	1.3	1.03	1.3	0.99	1.3	0.60	1.32	0.57	1.33
7 days	1.22	1.73	1.11	1.73	1.01	1.74	0.66	1.76	0.61	1.76
14 days	2.23	2.13	2.07	2.14	2.18	2.13	1.59	2.16	1.49	2.17
21 days	3.05	2.4	2.61	2.42	2.21	2.44	1.70	2.47	1.55	2.48
28 days	3.19	2.64	2.56	2.68	2.43	2.68	1.85	2.72	1.69	2.72
42 days	3.28	3.03	2.67	3.06	2.51	3.07	2.11	3.1	1.78	3.11
Note Lab = Laboratory compressive test result Model = Regression model results										

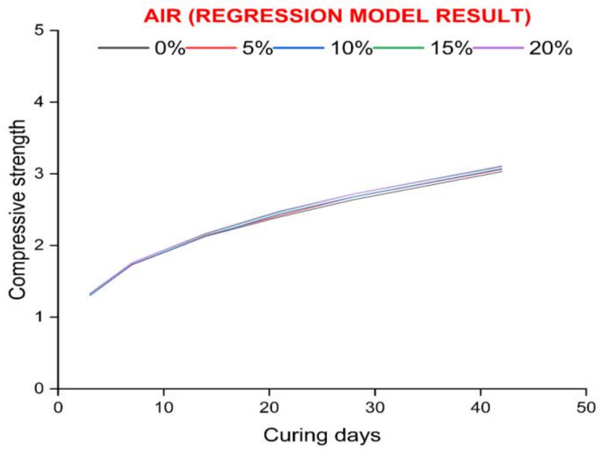

Fig 3.3: Graph of Curing Days Against Tensile Strength for Air-Cured Concrete Cylinder

Table 3.3 and fig 3.3 are the results of split tensile strength, and observed that strength decreased as RHA increases, Highest value: **3.28 N/mm²** (0% RHA, 42 days).

3.4.2 Water-Cured Cylinders

Table 3.4: Laboratory and Regression Model Tensile strength for Water-cured Concrete Cylinder

SPLIT TENSILE TEST (WATER CURED)

Model equation, σ = a + b*(Rha) + (t)**c
Rha is % replacement level, t is curing period, and a, b, c are regression parameters

	0%	0%	5%	5%	10%	10%	15%	15%	20%	20%
	Lab	**Model**	**Lab**	**Model**	**Lab**	**Model**	**Lab**	**Model**	**Lab**	**Model**
3 days	1.30	1.47	1.07	1.48	0.99	1.49	0.67	1.51	0.59	1.51
7 days	1.38	1.9	1.18	1.92	1.01	1.93	0.70	1.95	0.65	1.95
14 days	2.75	2.28	2.67	2.28	2.18	2.32	1.69	2.35	1.59	2.35
21 days	3.14	2.58	2.81	2.6	2.21	2.64	1.78	2.66	1.65	2.67
28 days	3.40	2.82	2.82	2.86	2.43	2.88	1.95	2.91	1.73	2.92
42 days	3.45	3.21	2.87	3.25	2.51	3.27	2.09	3.3	1.93	3.31

Note
Lab = Laboratory compressive test result
Model = Regression model results

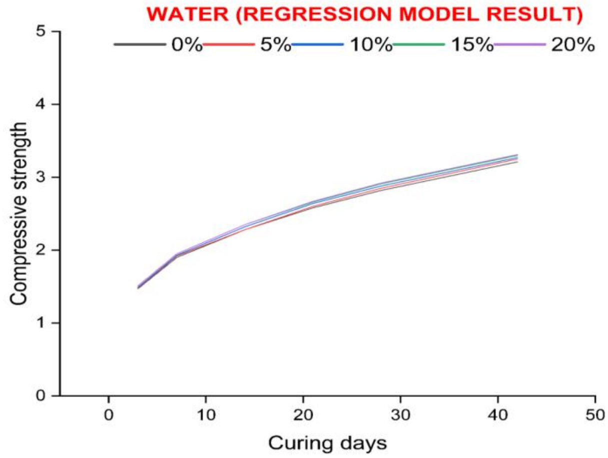

Fig 3.4: Graph of Curing Days Against Tensile Strength for Water-Cured Concrete Cylinder

Table 3.4 and fig 3.4 show the results of split cylinder tests cured in water, and found that 20% RHA showed better tensile results over time. Maximum strength: **3.45 N/mm²** (0% RHA, 42 days).

3.5 Summary of Results

Regression model (σ = a + b*(RHA) + t^c) aligned well with lab results which provided 95% confidence and reliability of the process.
The Model was run on laboratory experimental results and valid up to 42 days.

Water curing significantly improved both compressive and tensile strength, especially at 15% RHA

IV. CONCLUSION

Based on the findings from the study on the partial replacement of cement with Rice Husk Ash (RHA), the following conclusions can be drawn:
Slump test results revealed improved workability with increasing RHA content. Slump values for RHA replacement at 0%, 5%, 10%, 15%, and 20% were 10 mm, 10 mm, 15 mm, 20 mm, and 30 mm respectively, indicating enhanced workability compared to the control mix with 0% RHA.
The compressive strength of concrete increased with the inclusion of RHA, suggesting that RHA can be an effective partial replacement for cement in compressive applications.
However, the tensile strength exhibited a decline with RHA replacement when compared to the control mix, indicating that RHA may not contribute positively to the tensile properties of concrete.

5.0. Recommendations

i. Further long-term studies are recommended to determine the optimal RHA replacement levels for achieving maximum compressive strength, and to investigate potential durability or deterioration effects over time.

ii. Additional research should focus on the behaviour of RHA-modified concrete in tensile applications, as the current results suggest that improvements in compressive strength do not translate to similar gains in tensile strength.

iii. The availability and quality of RHA should be considered, ensuring that only suitable, properly processed RHA materials are used for concrete production.

iv. Comparative studies should be conducted to assess the strength variations among different locally sourced RHA materials to identify the most effective types for construction use.

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