INVESTIGATION INTO THE STRENGTH PROPORTIES OF HIGH-PERFORMANCE CONCRETE USING GUINEA CORN HUSK AND RICE HUSK ASHES AS PARTIAL REPLACEMENT FOR CEMENT

BY

HAMZAT TOHEEB ADISA

HND/23/CEC/FT/0101

SUBMITTED TO

THE DEPARTMENT OF CIVIL ENGINEERING KWARA STATE POLYTECHNIC ILORIN KWARA STATE NIGERIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF HIGHER NATIONAL DIPLOMA (HND) IN CIVIL ENGINEERING

JUNE, 2025.

DECLARATION

This is to certify that this research study was conducted by HAMZAT TOHEEB ADISA (HND/23/CEC/FT/0101) and had been read and approved as meeting the requirement for the award of Higher National Diploma (HND) in Civil Engineering, Institute of Technology, Kwara State Polytechnic Ilorin.

Signature………………………………… Date………………………………

ENGR. K. OLORUNFEMI

Project Supervisor

Signature………………………………… Date………………………………

ENGR. A. NAALLAH

Head of Department

Signature………………………………… Date………………………………

ENGR. DR. MUJEDU KASALI ADEBAYO

External Examiner

DEDICATION

This work is dedicated to the HAMZAT family in whole.

ACKNOWLEDGEMENT

First, I thank the Almighty God, the Creator of the universe and giver of life who has sustained the breath of life and health in me till now.

My sincere appreciation to my supervisor Engr. Mrs Olorunfemi for her time, dedication, patience, input and expertise in guiding me throughout the research this far. Your collective knowledge base, support and guidance have made this research comprehensive.

I also acknowledge University of Ilorin for allowing me to use their materials laboratory for concrete tests in particular Technician Engr. Yusuf for their availability and assistance to ensure specific milestones in this research were achieved.

I am also grateful to my brothers for his consistent motivation, feedback, and moral support during this study. Their companionship made the journey both productive and enjoyable.

Special thanks go to my family members whose unwavering support and assistance provided the foundation I needed to complete this project. Their encouragement and belief in my potential greatly contributed to my success.

To everyone who played a role in this journey, I extend my heartfelt thanks.

ABSTRACT

This study investigates the compressive strength of high-performance concrete (HPC) incorporating Rice Husk Ash (RHA) and Guinea Corn Husk Ash (GCHA) as partial replacements for ordinary Portland cement (OPC), with a focus on promoting sustainable construction practices in Nigeria. RHA and GCHA were combined at replacement levels of 5%, 10%, and 15% by weight of cement. Concrete specimens were cured for 7, 14, and 28 days, and tested for compressive strength. The control mix attained strengths of 25.4 N/mm², 25.6 N/mm², and 31.6 N/mm², while the 5% and 10% replacements attained comparable strengths of 31.6 N/mm² and 31.0 N/mm² respectively at 14 and 28days of curing. Although early-age strength was lower in the ash-blended mixes, strength significantly increased at later ages due to continued pozzolanic activity. The 15% replacement level resulted in reduced strength across all curing periods. Importantly, the use of RHA and GCHA both readily available agricultural waste products in Nigeria not only enhances concrete performance but also offers a low-cost alternative to cement, making it especially beneficial for affordable housing projects.

TABLE OF CONTENT

Title Page i

Declaration ii

Dedication iii

Acknowledgement iv

Abstract v

Table of Content vi

List of Figure xi

List of Table xiii

Chapter One: Introduction 1

1.1 Background of the Study 1

1.2 Statement of Problem 2

1.3 Aim and Objectives 3

1.3.1 Aim 3

1.3.2 Objectives	3
1.4 Justification	4
1.5 Scope of Study	4
Chapter Two: Literature Review	6
2.1 Theoretical Review	6
Chapter Three: Methodology	10
3.1 Materials Selection and Preparation	10
3.1.1 Cement (Ordinary Portland Cement)	10
3.1.2 Fine Aggregate	10
3.1.3 Coarse Aggregate	11
3.1.4 Guinea Corn Husk Ash (GCHA)	11
3.1.5 Rice Husk Ash (RHA)	12
3.1.6 Superplasticizer	12
3.1.7 Water	13

3.2 Physical and Chemical Properties 13

3.2.1 Sieve Analysis of Fine Aggregates and Coarse 13

3.2.2 Specific Gravity of Fine aggregates and coarse aggregates 14

3.2.3 Moisture content of fine aggregates 16

3.2.3 Silt content of fine aggregates 16

3.2.4 Slump Test 17

3.2.5 Chemical Properties of RHA and GCHA 18

3.2.6 Consistency and Setting Time Test of Cement 20

3.3 Mix Design 21

3.4 Mix Proportioning 22

3.4.1 Concrete Mixing and Casting 23

3.4.1.1 Batching 23

3.4.1.2 Mixing 24

3.4.1.3 Casting 24

3.4.1.4 Curing 25

3.5 Compressive Strength Test 25

3.5.1 Cubes Preparation 26

3.5.2 Testing Procedure 26

3.5.2.1 Load Application 26

3.5.2.2 Strength Determination 26

Chapter Four: Results and Discussion 28

4.1 Physical Properties of Materials Used in the Study 28

4.1.1 Sieve Analysis of Fine and Coarse Aggregates 28

4.1.2 Water Absorption Test 33

4.1.3 Moisture Content Test 34

4.1.4 Silt Content Test 36

4.1.5 Specific Gravity Test 36

4.1.6 Slump Test 39

4.1.7 Chemical Properties of RHA AND GCHA 40

4.1.8 Consistency and Setting time Test of Cement 43

4.2 Compressive Test 46

Chapter Five: Conclusion and Recommendation. 56

5.1 Conclusion 56

5.2 Recommendations 57

5.2.1 Recommendation for this Research. 57

5.2.2 Recommendation for Further Research 57

LIST OF FIGURES

Figure 3.1: Guinea Corn Husk Ash 11

Figure 3.2: Rice Husk Ash 12

Figure 3.3: Test on Sieve Analysis 14

Figure 3.4: Fine and Coarse Aggregate in SSD Condition 15

Figure 3.5: Sand Samples in Can for Moisture Content Test 16

Figure 3.6: Silt Content Test 17

Figure 3.7: Slump Test 18

Figure 3.8: Image of SEM Test on RHA 19

Figure 3.9: Batching of Cements and Aggregates 23

Figure 3.10: Casting of cube 24

Figure 3.11: Curing of Cubes 25

Figure 3.12: Crushing Test 27

Figure 4.1: %passing against sieve sizes for fine aggregates 30

Figure 4.2: %Passing Against Sieve Sizes for Coarse Aggregates 32

Figure 4.3: Slump Against Percentage Partial Replacement of Cement with RHA/GCHA 40

Figure 4.4: Components of RHA 43

Figure 4.5: Setting Time Against % Replacement of RHA+GCHA 45

Figure 4.6: Compressive Strength Against Curing Days 54

LIST OF TABLES

LIST OF TABLES

Table 3.1: Mix Proportion for One Cubic Metre of Concrete 22

Table:4.1: Sieve Analysis For Fine Aggregates Result 28

Table 4.2: Sieve Analysis For Coarse Aggregates Result 31

Table 4.3: Water Absorption Test Result 33

Table 4.4: Moisture Content Result 34

Table 4.5: Silt Content Result Test 36

Table 4.6: Specific Gravity Result 37

Table 4.7: Slump Test Result 39

Table 4.8: RHA Chemical Composition. 41

Table 4.9: GCHA Chemical Composition 42

Table 4.10: Setting Time And Consistency Test Result 44

Table 4.11: For Control 0% Replacement of GHCA and RHA 46

Table 4.12: For 5% Replacement of GHCA and RHA 48

Table 4.13: For 10% Replacement of GHCA and RHA 50

Table 4.14: For 15% Replacement of GHCA and RHA 52

LIST OF ABBREVIATION

ASTM	American Society for Testing Abd Materials
ACI	American Concrete Institution
BS	British Standard
BRE	Building Research Establishment
BS EN	British Standard European Norms
GCHA	Guinea Corn Husk Ash
RHA	Rice Hush Ash

CHAPTER ONE

INTRODUCTION

1.0 Background of the Study

High-Performance Concrete (HPC) is a specialized type of concrete engineered to meet specific performance requirements, such as high strength, durability, and workability. The demand for HPC has grown significantly due to its application in large-scale infrastructure projects, including highways, bridges, buildings, hydraulic structures, and industrial facilities (Choudhary et al., 2014). HPC typically achieves compressive strengths exceeding 40N/mm^2 reaching over 100N/mm^2 achieved from common mix grades for HPC such as M40, M60, M70, and higher. This remarkable strength enables the design of slender structural elements and the capacity to support large loads (Mehta et al., 2014).

HPC differs from normal concrete in its composition, performance, and application, normal concrete, composed of cement, water, aggregates, and minor admixtures, is widely used due to its affordability and availability. However, its limitations such as low tensile strength, high permeability, and reduced resistance to environmental degradation often restrict its suitability for demanding structural applications.

Concrete is the most widely used construction material globally, and its demand continues to rise. However, this demand comes with a significant environmental cost. The production of cement, a critical binder in concrete, accounts for approximately 8% of global CO_2 emissions. To address this environmental challenge, researchers have explored the use of alternative binders derived from waste materials to reduce reliance on conventional cement. Agricultural residues, when burned under controlled conditions, produce ashes with pozzolanic properties (rich in silica and alumina), which can enhance the strength and durability of concrete (Mehta and Monteiro, 2006).

Guinea Corn Husk Ash (GCHA) and Rich Husk Ash(RHA) are pozzolanic materials obtained from the controlled combustion of guinea corn husks and rice husk respectively, agricultural by-products of guinea corn and rice. This ash is rich in amorphous silica, making it suitable as a partial replacement for cement in concrete. Pozzolanic materials like GCHA and RHA improve concrete properties by reacting with calcium hydroxide ($Ca(OH)_2$), a by-product of cement hydration. This reaction forms additional calcium silicate hydrate (C-S-H) gel, which is the primary compound responsible for concrete's strength. Consequently, GCHA contributes to improved strength, durability, and workability.

While materials like fly ash and silica fume are well-established in concrete applications, research on GCHA and RHA remains limited. Its utilization presents a significant opportunity for sustainable construction practices by repurposing agricultural waste and reducing the carbon footprint associated with cement production.

1.2 Statement of Problem

Cement production accounts for 8% of global carbon dioxide emission which can pose health hazards by air pollution and global warming, substituting GCHA and RHA as a partial replacement for cement could reduce carbon dioxide emission percentage. Guinea corn husks and rice husk which are by-product of cereal production are generated in large quantities across many regions. These husks are often discarded or burned in open fields, contributing to environmental pollution and resource wastage. Preliminary studies suggest that when properly processed, Guinea corn husk ash (GCHA) and Rice husk ash (RHA) exhibits pozzolanic properties, which make it a potential substitute for a portion of cement in concrete which solve pollution problems.

Furthermore, while high-performance concrete (HPC) is known for its superior mechanical properties and durability compared to traditional concrete, its production requires advanced materials and techniques, often making it expensive and less accessible. Exploring cost-effective and sustainable alternatives such as GCHA and RHA in HPC could address this challenge, but there is little existing research on this specific application.

1.3 Aim and Objectives

1.3.1 Aim

Investigation into the strength properties of High-performance concrete using Guinea corn husk ash and Rice husk ash.

1.3.2 Objectives

1. To determine the physical and chemical properties of burnt GCHA and RHA

2. To determine the optimum GCHA and RHA replacement percentage for peak strength performance.

1.4 Justification

This research contributes to sustainable construction practices by evaluating a waste product that is both widely available and environmentally friendly. If GCHA and RHA proves effective, it could reduce cement demand and offer a cost-effective solution for concrete production, especially in regions where guinea corn is cultivated. This aligns with the global push toward sustainable development in construction, as discussed in *Shi et al. (2011).*

1.5 Scope of Study

This research focuses on the evaluation of Guinea corn husk ash (GCHA) and Rice husk ash(RHA) as a partial replacement for cement in high-performance concrete (HPC). This involves investigating the mechanical and durability properties of HPC incorporating varying percentages of GCHA and RHA respectively. The study will examine key performance parameters such as compressive strength under different curing periods and environmental conditions.

The experimental work will involve producing HPC with GCHA and RHA replacement levels ranging from 5% to 20% and conducting tests such as durability and compressive strength tests. These tests are critical for understanding the mechanical behavior of the modified HPC, as reported in studies like Elahi *et al. (2023*), which emphasized the impact of pozzolanic materials on improving concrete properties under varying conditions. By evaluating these parameters, the study aims to establish an optimal replacement percentage of GCHA and RHA that balances mechanical performance, durability, and environmental benefits.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Review

High-Performance Concrete (HPC) is a specialized type of concrete designed to provide superior mechanical and durability properties compared to conventional concrete. It is characterized by its high strength, excellent durability, and superior workability. Achieving these properties typically involves a low water-to-cement ratio, the use of chemical admixtures such as superplasticizers, and the incorporation of supplementary cementitious materials (SCMs). The primary benefits of HPC include improved structural performance, extended service life, and reduced maintenance requirements, making it an ideal choice for demanding construction applications like bridges, tunnels, and high-rise buildings (Kannan, 2017).

Concrete, the fundamental material for HPC, is a composite made from fine and coarse aggregates bonded together with a binder, typically Portland cement, and water. Upon mixing and hydration, cement reacts with water to form a hard, stone-like matrix that binds the aggregates together, providing the material with its strength and durability. Concrete's versatility, availability, and adaptability make it the most widely used construction material globally. According to Neville and Brooks (2010) in *Concrete Technology*, the properties of concrete can be tailored by altering mix proportions and incorporating additives such as SCMs, making it suitable for a wide range of applications.

SCMs, when used in conjunction with Portland cement, contribute to the properties of the hardened concrete through hydraulic or pozzolanic activity. Common SCMs include fly ash, silica fume, and ground granulated blast furnace slag. These materials not only enhance the performance of concrete but also contribute to sustainability by reducing the carbon footprint associated with cement production. Recent studies have highlighted the potential of agricultural waste ashes as viable SCMs, offering both environmental and economic benefits (Sata et al., 2007).

The utilization of agricultural waste ashes, such as rice husk ash and palm oil fuel ash, has been extensively studied. These ashes are rich in silica and exhibit pozzolanic properties, which improve the microstructure and mechanical properties of concrete. For instance, rice husk ash has been shown to enhance compressive strength and durability, providing a basis for exploring other agricultural residues like guinea corn husk ash (Subbulakshmi et al., 2014).

Rice Husk Ash (RHA) is an agro-waste material rich in amorphous silica, which makes it an effective pozzolan in concrete production (Zhang & Malhotra, 1996). The properties of RHA depend significantly on the burning temperature and grinding process. RHA produced at temperatures below 700°C retains high pozzolanic activity due to its amorphous silica content (Ganesan et al., 2008). Several studies have demonstrated that partial replacement of cement with RHA in the range of 5–20% enhances the compressive strength of concrete at later curing ages (Chowdhury et al., 2017). Additionally, RHA-modified concrete exhibits improved durability, reducing chloride penetration and sulfate attack risks (Gutiérrez et al., 2018). Guinea Corn Husk Ash (GCHA) is another agro-based pozzolan that has been explored in recent studies. It contains silica and alumina, which contribute to its cementitious properties when finely ground (Olutoge et al., 2015). Controlled combustion and processing enhance its reactivity, making it a viable partial replacement for cement. Research by Akinwumi et al. (2019) reported that incorporating GCHA in HPC at replacement levels between 5% and 15% leads to comparable or even superior compressive strength compared to control specimens. However, excessive replacement (beyond 20%) may result in a reduction in strength due to increased porosity.

Several researchers have examined the combined effect of RHA and GCHA on the compressive strength of HPC. Studies indicate that a combination of these materials enhances the mechanical properties of concrete due to synergistic pozzolanic reactions (Bakar et al., 2010). According to Nair et al. (2013), concrete mixes incorporating RHA and GCHA at optimized replacement percentages achieve higher strength compared to plain OPC concrete. The fine particle size of RHA contributes to increased packing density, while GCHA provides additional silica for C-S-H formation, resulting in improved strength development. The curing period significantly influences the compressive strength of HPC containing RHA and GCHA. Studies have shown that concrete incorporating pozzolanic materials tends to exhibit lower early strength but gains significant strength at later ages due to ongoing pozzolanic reactions (Paya et al., 2002). For instance, Khan et al. (2020) observed that RHA-blended concrete displayed a noticeable increase in strength between 14 and 28 days, surpassing the strength of control specimens.

The utilization of GCHA and RHA in concrete production offers significant environmental benefits by reducing agricultural waste and lowering the carbon footprint of cement manufacturing. Economically, it provides a cost-effective alternative to conventional SCMs, particularly in regions where guinea corn is abundantly cultivated. This aligns with global sustainability goals by promoting the use of renewable and locally available resources in construction (Ndububa & Nurudeen, 2015; Kannan, 2017).

CHAPTER THREE

METHODOLGY

The methodology process is structured to ensure a systematic approach to evaluating the compressive strength of high-performance concrete (HPC) containing burnt guinea corn husk ash (GCHA) and rice husk ash (RHA).

3.1 Materials Selection and Preparation

To ensure the quality and consistency of the HPC mix, the materials used were carefully selected and prepared as follows:

3.1.1 Cement (Ordinary Portland Cement)

Cement of grade 42.5R was used as the primary binder, conforming to ASTM C150 standards, ensuring adequate hydration and strength development.

3.1.2 Fine Aggregate

It was sourced and sieved to remove organic matter and clay, meeting BS 882 requirements for quality.

3.1.3 Coarse Aggregate

Coarse aggregates used were obtained from graded crushed stones, with fractions sizes ranging from 10mm to 20mm. The required quantity was purchased from reputable quarries with crushing plants within Ilorin,kwara state Which was used to enhance the strength and durability of the concrete.

3.1.4 Guinea Corn Husk Ash (GCHA)

The husk was collected from, dried thoroughly to reduce moisture content, and burnt in a controlled environment at a temperature of 600–700°C. The resultant ash was finely ground to pass through a 75-micron sieve, ensuring better pozzolanic activity.

Figure 3.1: Guinea Corn Husk Ash

3.1.5 Rice Husk Ash (RHA)

The rice husk was collected from a rice refining industry at Offa, Kwara State and underwent controlled burning at temperatures below 700°C to retain high amorphous silica content. It was then ground and sieved to 75 microns to ensure optimal reactivity in the cementitious matrix.

Figure 3.2: Rice Husk Ash

3.1.6 Superplasticizer

Admixture was used to improve the workability of the concrete.

3.1.7 Water

Clean, potable water was obtained around the school premises and used to facilitate hydration and chemical reactions in the cementitious materials.

3.2 Physical and Chemical Properties

Some physical properties tests were conducted on the various materials include sieve analysis, specific gravity, moisture content, consistency and setting time of cement (with varying partial replacement of RHA and GCHA, silt content, and scanning electron microscopy (SEM).

3.2.1 Sieve Analysis of Fine Aggregates and Coarse Aggregates

Sieve analysis according to BS 812 was carried out to determine the size particle distribution of both fine and coarse aggregates. The procedure involved passing the dried samples through a set of standard sieves arranged in descending order of size between sizes (8mm to 150micron), the assembled sieves were shaken manually for sufficient time to separate in different fraction sizes. The weight retained on each sieve was recorded, and the cumulative percentage passing was calculated to determine the grading of the aggregates. A graph of cumulative percentages passing was against the sieve sizes was plotted.

Finesse Modulus= Σ% cumulative weight retained btw 80mm to 0.150mm/100 (fine aggregates)

Figure 3.3: Test on Sieve Analysis

3.2.2 Specific Gravity of Fine Aggregates and Coarse Aggregates

Specific gravity was conducted according to BS 812-2. Before testing for specific gravity, the aggregates were first brought to **Saturated Surface Dry (SSD)** condition. For fine aggregates the sand was soaked in water for 24 hours. After that, it was spread out and air-dried gently while being stirred occasionally in order to reach a point in which the sand no longer looked shiny or wet on the outside, but still felt moist inside. While for coarse aggregates, the aggregates were soaked for the same amount of time, then dried using a clean, dry towel to remove any surface moisture. After the aggregates were brought to SSD condition the test was carried out to test how heavy the materials are compared to the same volume of water. The weight of measuring cylinder was recorded as W1. The sample were filled into the cylinder and weighed; the weight was recorded as W2(weight of cylinder + sample). The cylinder was filled gradually with distilled water to gauge mark soon after the end of soaking air entrapped and bubbles on the surface of the sample was removed by shaking the cylinder and weighed to be W3(weight of cylinder + sample + water) after which the cylinder was emptied and cleaned. The cylinder was then filled with water to the brim and weighed as W4(weight of cylinder + water) and a formula was used to calculate the specific gravity.

Specific gravity= W2-W1/(W4-W1)-(W3-W2)

Figure 3.4: Fine and Coarse Aggregate in SSD Condition

3.2.3 Moisture content of fine aggregates

The moisture content of both fine aggregates was determined to adjust the water-cement ratio in the concrete mix. The test involved weighing the aggregate samples before and after oven drying at 105°C for 24 hours. The difference in weight was used to calculate the moisture percentage.

Moisture content (%) = Weight of moisture/Dry weight of sand x 100

Figure 3.5: Sand Samples in Can for Moisture Content Test

3.2.3 Silt content of fine aggregates

The silt content of the fine aggregate was determined to assess the level of impurities. A 50ml measured quantity of sand was mixed with a salt-water solution of 100ml (10% of volume of water was measured for the salt added) in a graduated cylinder of 250ml, shaken thoroughly, and allowed to settle for 3 hours. The thickness of the silt layer was compared to the total height of the sand layer to determine the percentage of silt present.

Silt content (%) = (Volume of silt / Volume of sand) x 100

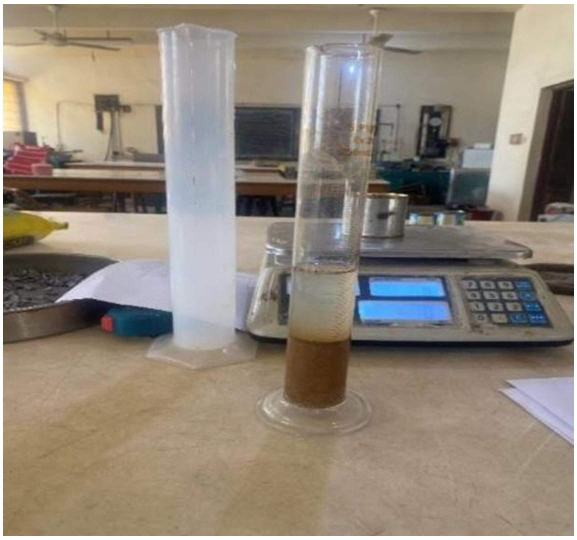

Figure 3.6: Silt Content Test

3.2.4 Slump Test

Slump test was conducted to determine the workability or consistency of concrete from a freshly mixed batch. The concrete mix was placed in a slump cone with a bottom diameter of 200 mm and top diameter of 100 mm placed on smooth floor while mixing is done. The concrete was placed in three equal layers and each layer tamped evenly with 25 strokes using a tampering rod. Excess concrete was removed and the surface leveled with a trowel. The mould was raised slowly in vertical direction. Slump was measured as the difference between height of the mould and the height of concrete specimen. The slump readings were read directly from a tape rule and recorded in millimeters of subsidence of the mix. The readings were plotted on a graph for the various mixes for comparison (0,5,10,15% partial replacement of cement with RHA/GCHA).

Figure 3.7: Slump Test

3.2.5 Chemical Properties of RHA and GCHA

The chemical composition of Rice Husk Ash (RHA) and Guinea Corn Husk Ash (GCHA) was determined Scanning Electron Microscopy (SEM) at Kwara State University, Malete and measured on a Scanning Electron Microscope (ASPEX 3020) at 16.0 kV accelerating voltage. The samples were coated with gold using Balzer's sputtering device before observing them in the microscope. The ashes were initially oven-dried to remove moisture and then sieved through a 75 µm mesh to ensure uniformity.

Representative samples of each ash were placed in sample holders and analyzed under an electron microscope to determine the weight percentage of key elements such as Silicon (Si), Calcium (Ca), Iron (Fe) and other trace elements. The resulting data was used to classify the pozzolans in accordance with ASTM C618, which categorizes pozzolanic materials as either Class F or Class C based on their silica, alumina, and calcium content.

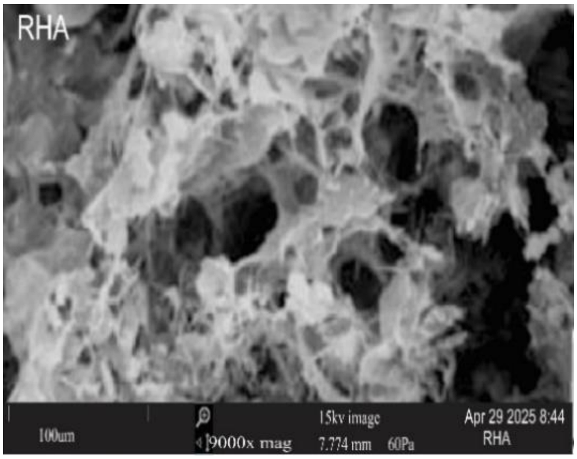

Figure 3.8: Image of SEM Test on RHA

3.2.6 Consistency and Setting Time Test of Cement

This test investigates the effect of partially replacing Ordinary Portland Cement (OPC) with a combined pozzolanic mixture of Rice Husk Ash (RHA) and Guinea Corn Husk Ash (GCHA) at 5% varying percentages up to 15% by determining the initial and final setting time of cement paste using Vicat apparatus to BS 4550 Part 3.5-1978. 400g of cement was mixed with water, starting with 25% water-cement ratio and thoroughly mixed to form a consistent paste within 10seconds. The paste was then filled into a vicat mould on a glass plate and leveled mould was placed under a vicat plunger which was gently lowered to touch the surface and then released to measure the penetration depth. This process was repeated with varying water content until a penetration of about 33mm-35mm was achieved indicating the standard consistency of the cement paste.

Cement paste was prepared with 400g of cement and mixed with water equivalent to 0.85P by weight of cement serving as the control sample. Other samples were prepared with partial replacement of cement with RHA and GCHA at varying percentages of 5%, 10%, and 15%. The Gauge time was 3-5 minutes. A stop watch was started immediately water was added to the sample and the time recorded at t_1.The Vicat mould was filled with cement paste and smoothened on the surface to form a test block. Initial setting time was determined by lowering a plunger with a needle and recording the penetration of the needle into the test block. This was repeated every 2 minutes until the needle failed to pierce the test block for about 5 mm. This time was recorded as t_2.

Final setting time was determined by replacing the needle of the Vicat apparatus with an annular attachment. Final setting time t_3 was determined as the time at which the needle makes an impression and the annular attachment fails to make an impression on the surface of the test block. The setting times were determined for unblended cement paste and also for cement paste with cement partially replaced with various percentages of rice straw ash.

3.3 Mix Design

The mix design was done according to Building Research Establishment (BRE, 1988) method with a target characteristic strength of 40N/mm2 at 28 days. The choice of class concrete strength was informed by compressive strengths used by previous researchers:

Khusbu and Sharma (2014) used a concrete strength of 32 N/mm2, Faseyemi (2012) used a concrete strength of 30 N/mm2, Olutoge et al. (2012) used a concrete strength of 34 N/mm2. The BRE method of design involved the selection of correct proportions of cement, fine aggregate and water to produce concrete having specified properties namely: workability of fresh concrete, compressive strength at specified age and durability by specifying minimum cement content and/or maximum free water/cement ratio.

CONCRETE MIX DESIGN

1) Building Research Establishment (BRE) otherwise called DOE – U.K

BRE METHOD

The code used for this method is BRE 1997.

Data given:

Characteristic strength of concrete, f_c=40N/mm^2

Maximum size of aggregate = 12mm

Specific gravity of cement = 3.15

Specific gravity of F. A = 2.65

Specific gravity of C. A = 2.7

% passing sieve no. 600µm for F.A = 72%

Slump = 50mm

From fig 3, standard deviation, s = 8N/mm^2

Cement grade = 42.5

Target mean strength, $f_m = f_c + ks$ (1)

From the normal distribution, at 5% defective,

k = 1.64

Substituting k and s in eq. (1) $f_m = 40 + (1.64 * 8) = 53.12\text{N/mm}^2$

From table 2, approximate compressive strength with w-c ratio of 0.5 = 49N/mm^2 (crushed)

From fig. 4, free w-c ratio = 0.47

Using interpolation method for 12mm size for aggregate

From table 3, free water content for F.A, W_f = 186.25kg/m^3

And free water content for C.A, W_c = 215kg/m^3

But free water content, $W = \frac{2}{3}W_f + \frac{1}{3}W_c$ (2)

$$W = \left(\frac{2}{3} * 186.25\right) + \left(\frac{1}{3} * 215\right) = 195.83\text{kg/m}^3$$

Cement content,

$$C = \left(\frac{Free\ water\ content}{Free\ water - cement\ ratio}\right)$$

$$C = \frac{195.83}{0.47} = 416.66\text{kg/m}^3$$

From fig. 5, using S.G of maximum aggregate of 2.7 and W of 195,

Wet density of concrete = 2390kg/m^3

Total aggregates = Wet density – cement content – water content

= 2390 – 416.66 – 195.83 = 1777.51kg/m^3

From fig. 6, proportion of fine aggregate = 44%

Therefore, fine aggregate content = 0.44X1777.51 = 782.10kg/m^3

Coarse aggregate content = 1777.51 –782.10 kg/m^3 = 995.41kg/m^3

Since the maximum aggregate size is 12mm, the ratio of 10mm to 20mm will be 1:2.

Therefore, table below will be obtained.

Table 3.0: Mix Proportion for One Cubic Metre of Concrete

Quantities	**Cement (kg)**	**Water (kg or lit)**	**F.A (kg)**	**C.A (kg)**		
				10mm	**20mm**	**40mm**

per m^3	416.66	195.83	782.10	331.80	663.61	0
Ratio	1	0.47	1.88	2.39		

3.4 Mix Proportioning

A well-structured mix design was essential to produce HPC with varying percentages of cement replacement by GCHA and RHA. The absolute volume method was applied to proportion the materials accurately. The mix design followed **ACI 211.4R-08 guidelines**, ensuring an optimal balance between workability, strength, and durability.

Four mix variations were prepared:

- Control mix (100% Ordinary Portland Cement)
- Partial cement replacement mixes with 5**%, 10% and 15% GCHA and RHA.**

3.4.1 Concrete Mixing and Casting

The concrete mixing and casting process were executed meticulously to ensure uniform distribution of materials and eliminate inconsistencies in strength development.

3.4.1.1 Batching

Each material was precisely weighed using a digital scale in relation to the mix ratio. Fine and coarse aggregates were sun-dried before use to eliminate moisture variations.

Figure 3.9: Batching of Cements and Aggregates

3.4.1.2 Mixing

After dried the materials (cement, GCHA, RHA, fine aggregate, and coarse aggregate) were mixed for two minutes to ensure uniform distribution, water was then gradually added while mixing continued for an additional five minutes to achieve a homogenous mix.

3.4.1.3 Casting

The fresh concrete was poured into 100mm × 100mm × 100mm cube molds in three layers, each layer was compacted using a tamping rod (25 strokes per layer) to eliminate air voids and ensure uniform compaction. A total of 24 cubes were casted for replacement mixes with 5%, 10% and 15%, of GCHA and RHA in relation to the curing 7, 14, and 28 days.

Figure 3.10: Casting of cubes

3.4.1.4 Curing

The cubes were demolded after 24 hours and placed in a curing tank with clean water. Curing was done for 7, 14, and 28 days to allow for optimal hydration and strength gain.

Figure 3.11: Curing of Cubes

3.5 Compressive Strength Test

The compressive strength test was conducted in accordance with **BS EN 12390-3:2019** standards. This test measures the ability of the concrete to withstand compressive loads, which is a crucial parameter in structural applications.

3.5.1 Cubes Preparation

The cured concrete cubes were removed from the water and allowed to surface-dry before testing.

3.5.2 Testing Procedure

A compression testing machine (1560 KN capacity) was used to apply compressive loads. Each cube was centered on the loading platform, ensuring even distribution of the applied force.

3.5.2.1 Load Application

The load was applied uniformly until the cube failed.

3.5.2.2 Strength Determination

The maximum failure load was recorded and compressive strength was calculated using the formula:

$$\mathbf{fc = f/A}$$

where:

fc = Compressive strength (N/mm^2)

P = Maximum load applied (N)

A = Cross-sectional area of the cube (mm²)

Figure 3.12: Crushing Test

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical Properties of Materials Used in the Study

4.1.1 Sieve Analysis of Fine and Coarse Aggregates

The results of sieve analysis of fine and coarse aggregates are shown in the table and the graph plotted in form semi-log graph of cumulative % passing versus sieve size is illustrated in Figure below:

Table:4.1: Sieve Analysis Result for Fine Aggregates

Sieve sizes (mm)	Weight of sand retained (g)	% Weight retained (g)	% cumulative weight retained (g)	% Passing
8.0	1.5	0.15	0.15	99.85
4.0	18.0	1.8	1.95	98.05

2.36	37.5	3.75	5.7	94.3
1.0	138.0	13.82	19.52	80.48
0.500	242.5	24.27	43.79	56.21
0.250	365.5	36.59	80.38	19.62
0.150	134.0	13.41	93.79	6.21
Pan	62.0	6.21	100	0
	999		Σ=245.3	

Finesse modulus=Σ% cumulative weight retained btw 80mm to 0.150mm/100

Finesse modulus= 245.3/100= 2.453 ̰2.5

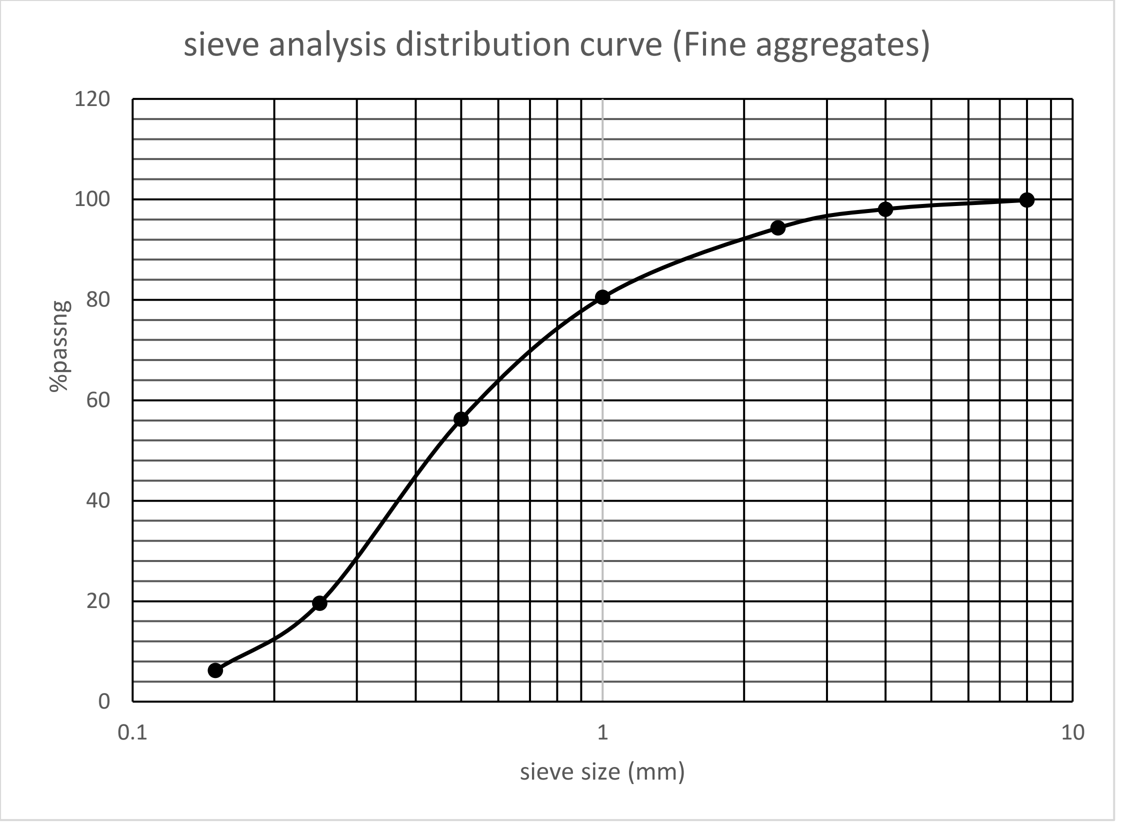

Figure 4.1: %Passing Against Sieve Sizes for Fine Aggregates

The finesse modulus calculated above supports it is a fine sand corresponding to sand classification based on grain size 2.2-2.6. The figure above shows the grading of fine aggregates. It was observed that the grading curve fell within the grading envelope specified. This implies that the particle sizes within the fine aggregate range were available in recommended percentage ranges. This ensured that the resultant concrete was neither susceptible to bleeding nor exerted high water demand owing to the large surface area of fine aggregate particles.

Table 4.2: Sieve analysis for coarse aggregates

Sieve sizes (mm)	Weight of sand retained (g)	% Weight retained (g)	% cumulative weight retained (g)	% Passing
31.5	0	0	0	100
16	0	0	0	100
8	908.4	90.88	90.88	9.12
4	89.5	8.95	99.83	0.17
2.36	1.2	0.12	99.95	0.05
Pan	0.5	0.05	100	0
	999.6		Σ=290.66	

Finesse modulus=Σ% cumulative weight retained btw 31.5mm to 2.36mm/100

Finesse modulus= 290.66/100= 2.9066̰2.91

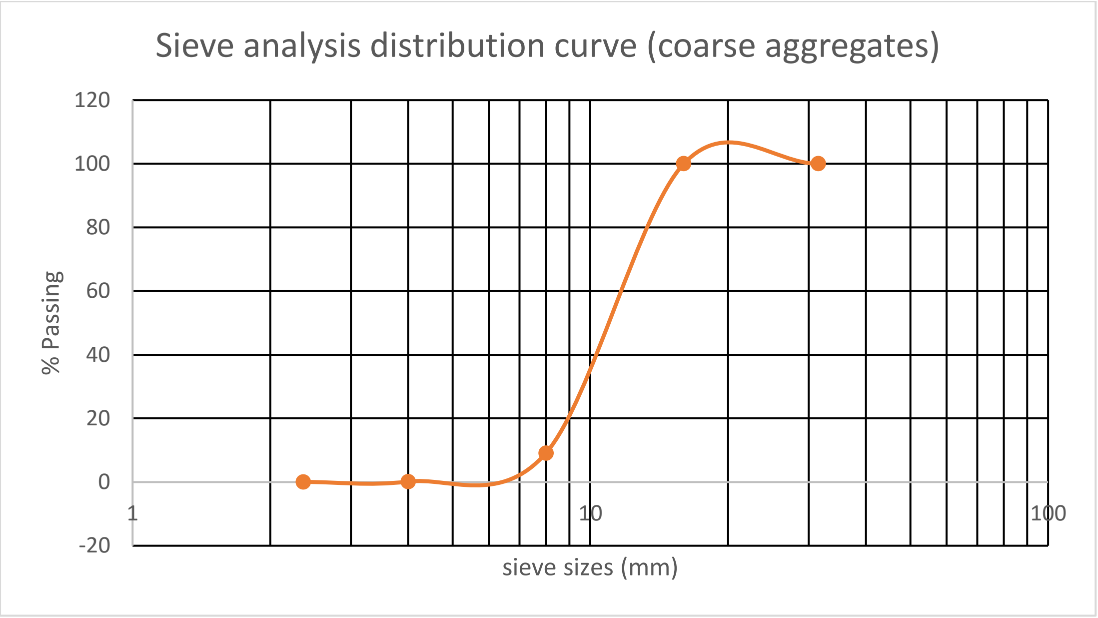

Figure 4.2: %Passing Against Sieve Sizes for Coarse Aggregates

The results above show that the grading curve was found to fit within the grading envelope specified. The aggregate did not have gap in gradation of particle size. The grading curve was found to fall within the specified grading envelope. The availability of various particle sizes ensured good particle interlock in the cement matrix with smaller sized particles fitting into voids left between larger sized particles. This ensured a dense concrete matrix without many voids hence maximized load bearing capacity of the concrete (Buertey et al., 2018).

4.1.2 Water Absorption Test

Water absorption tests were carried out on both fine and coarse aggregates to determine the amount of water they can retain. The results after the test are shown below:

Table 4.3: Water Absorption Test Result

Description	Coarse aggregate	Fine aggregate
Weight of sample A (g)	1000	500
Weight of sample after 24hr in the oven B (g)	1002.5	512.5
Weight of water absorbed C (g)	2.5	12.5

Water absorption capacity (%) =C/A X 100	0.25	2.5

The water absorption values were within acceptable limits generally less than 3% for coarse aggregates and 2% for fine aggregates is considered satisfactory (Neville, 2011). Higher absorption indicates more porous aggregates, which may lead to reduced strength and durability if not properly accounted for. The obtained values were used to adjust the water content of the mix to maintain consistent workability and effective water-cement ratio. Aggregates with high water absorption can draw water from the mix, resulting in insufficient hydration and lower strength (Mehta & Monteiro, 2014).

4.1.3 Moisture Content Test

The moisture content of the fine aggregate was determined using the oven-drying method in accordance with BS 812-109:1990. The presence of moisture in aggregates influences the water-cement ratio and, consequently, the strength and durability of concrete. The results show in the table below:

Table 4.4: Moisture Content Result

Description	Sample A	Sample B

Weight of Can (g)	25.0	24.5
Weight of Can + moist sand (g)	117.0	107.0
Weight of Can + Dry sample (g)	112.0	102.5
Weight of Dry Sample (g)	87.0	78.0
Weight of moisture (g)	5.0	4.5
Moisture content (%) = Weight of moisture/Dry weight of sand x 100	5.8	5.8
Average Moisture Content (%)	5.8	

The moisture content of the sand sample was within the acceptable range of 2–6% for natural sand (Neville, 2011). The measured moisture content was considered during the batching process to maintain a consistent water-cement ratio and avoid bleeding or segregation in the concrete mix.

4.1.4 Silt Content Test

After the test was carried out the volume of silt was measured as 2.5ml while the volume of sand is measured as 80ml

Table 4.5: Silt Content Result Test

Sample	**Height of silt Layer(mm)**	**Height of Sand Layer (mm)**	**Silt Content (%)**
Sand	2.5	80	3.1

Silt Content (%) = 2.5 / 80 x 100 = 3.1%

The silt content obtained was below the 6% limit recommended by IS 2386 (Part I) for fine aggregates used in concrete. A low silt content is beneficial for achieving good bond strength and overall concrete performance.

4.1.5 Specific Gravity Test

The data below was given after the test was carried out

Table 4.6: Specific Gravity Result

Description	Coarse agg A	Coarse agg B	Fine agg A	Fine agg B
Weight of sample (g)	300	300	264	264
Weight of measuring cylinder (g) W1	134.5	134	134	134
Weight of M+sample (g) W2	434.5	434	398	398
Weight of M+S+Water (g) W3	986.5	989	960	962
Weight of M+Water (g) W4	797.5	799	800	799.5
Specific Gravity= W2-W1/(W4-W1)-(W3-W2)	2.70	2.73	2.54	2.60

Average specific gravity (Fine Aggregates) = 2.54+2.60=2.57

Average specific gravity (Coarse Aggregates) =2.70+2.73=2.715

The values above fall within the typical ranges for natural aggregates used in concrete production. According to the American Concrete Institute (ACI) and ASTM standards, the specific gravity of natural fine aggregates generally ranges from 2.5 to 2.8, while that of coarse aggregates typically ranges from 2.6 to 2.9 (ACI Education Bulletin E1-07, 2007).

The fine aggregate's specific gravity of 2.57 suggests it is likely composed of quartz-rich sand, common in many regions, including Nigeria. This observation aligns with findings from Adekunle and Okeke (2018), who reported that fine aggregates sourced from Ibadan and surrounding areas had specific gravities between 2.55 and 2.65 (Nigerian Journal of Technological Development, Vol 15, No.2,2018).

The coarse aggregate's specific gravity of 2.715 indicates a dense material such as granite, which are widely used in concrete due to their high load-bearing capacity. Similar values were reported by Ali and Kwan (2020), who examined coarse aggregates from multiple sources in West Africa and found specific gravity values ranging from 2.65 to 2.75 (International Journal of Civil Engineering and Technology, Vol. 11, Issue 5, 2020).

These specific gravity values confirm that the aggregates tested are suitable for structural concrete applications and can be reliably used in mix design calculations to ensure strength, durability, and economy.

4.1.6 Slump Test

Upon mixing the concrete with various percentages of cement replacement levels, the results of slump test are illustrated by this Figure below:

Table 4.7: Slump Test Result

Mix ID	% Replacement	Slump (mm)	Slump Type
Control	0%	44	True
Mix	5% GCHA + RHA	37	True
Mix	10% GCHA + RHA	32	True
Mix	15% GCHA + RHA	27	True

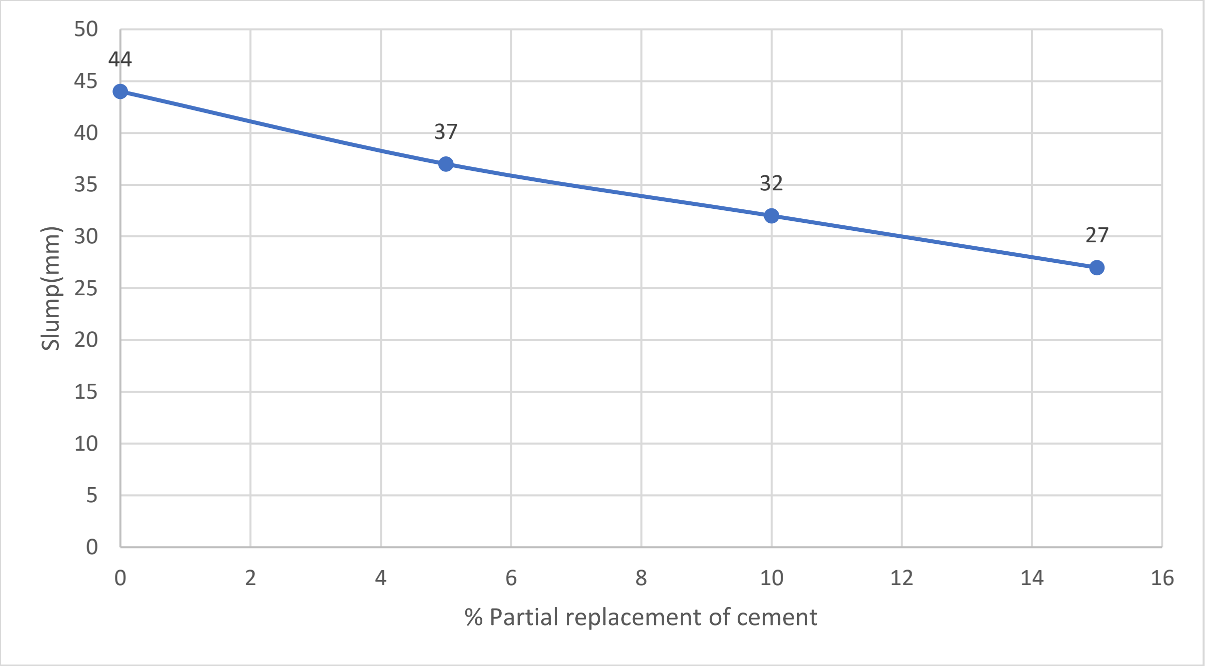

Figure 4.3: Slump Against Percentage Partial Replacement of Cement with RHA/GCHA

A decrease in slump was observed with increasing GCHA and RHA content, indicating reduced workability. This is consistent with findings by Habeeb and Fayyadh (2009), who noted that RHA increases water demand due to its high surface area and porosity. Despite the reduced slump, all mixes remained workable for compaction and placement.

4.1.7 Chemical Properties of RHA AND GCHA

After the test was conducted the results below were found out the components present in the pozzolans;

Table 4.8: RHA Chemical Composition

Element	Symbol	Percentage (%)
Silicon	Si	56.0
Magnesium	Mg	3.0
Oxygen	O	6.0
Carbon	C	11.5
Iron	Fe	11.3
Gold (trace)	Au	1.2
Calcium	Ca	15.0

The chemical analysis of RHA reveals a high silicon content (56%), indicating strong pozzolanic activity. The presence of calcium (15%) supports additional binding capacity. Iron and carbon contents suggest incomplete combustion or organic remains. Gold trace is uncommon and may be due to contamination. RHA is classified as a Class F pozzolan according to ASTM C618.

Table 4.9: GCHA Chemical Composition

Element	Symbol	Percentage (%)
Silicon	Si	41.0
Magnesium	Mg	2.8
Oxygen	O	5.5
Carbon	C	16.0
Iron	Fe	9.0
Potassium	K	3.5
Calcium	Ca	22.0

The GCHA sample contains moderate silicon (41%) and high calcium (22%), suggesting borderline pozzolanic and cementitious properties. The high carbon content indicates incomplete combustion, requiring further processing for optimal performance. Based on its chemical profile, GCHA is classified as a Class C pozzolan according to ASTM C618.

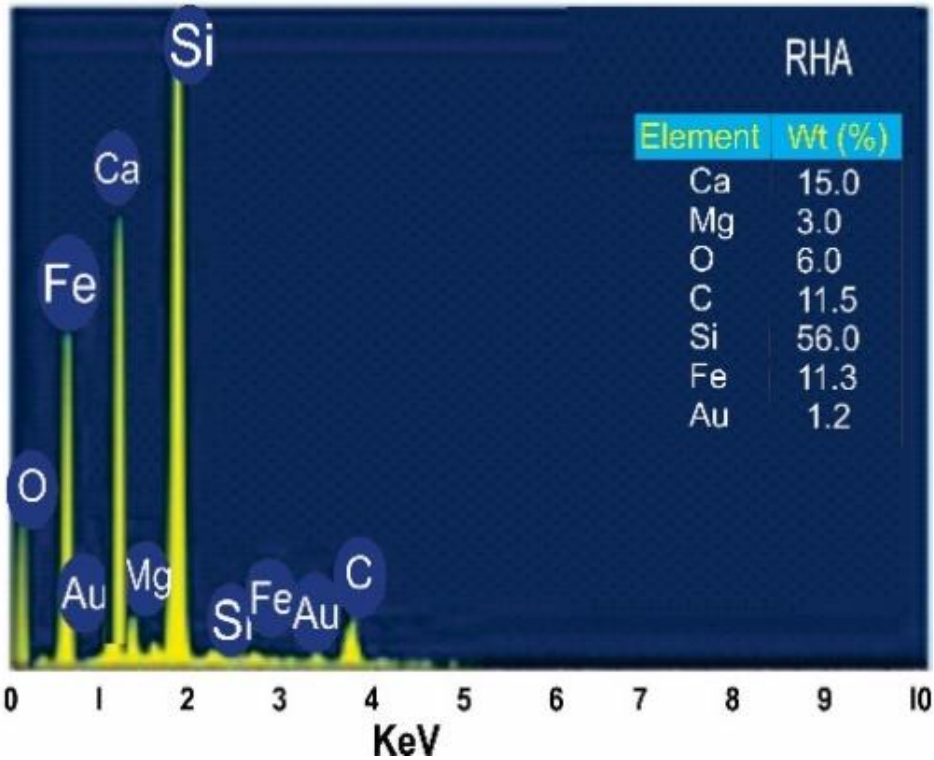

Figure 4.4: Components of RHA

4.1.8 Consistency and Setting time Test of Cement

The test was carefully carried out using a vicat apparatus according to BS 4550.The result of the consistency and setting time are in the table below;

Table 4.10: Setting Time And Consistency Test Result

Replacement Level (%)	Constituents	Standard Consistency (%)	Initial Setting Time (mins)	Final Setting Time (mins)
0% (Control)	100% Ordinary Portland Cement (OPC)	34	45	280
5%	95% OPC + 5% (RHA + GCHA)	33	50	300
10%	90% OPC + 10% (RHA + GCHA)	34	57	330

15%	85% OPC + 15% (RHA + GCHA)	35	65	360

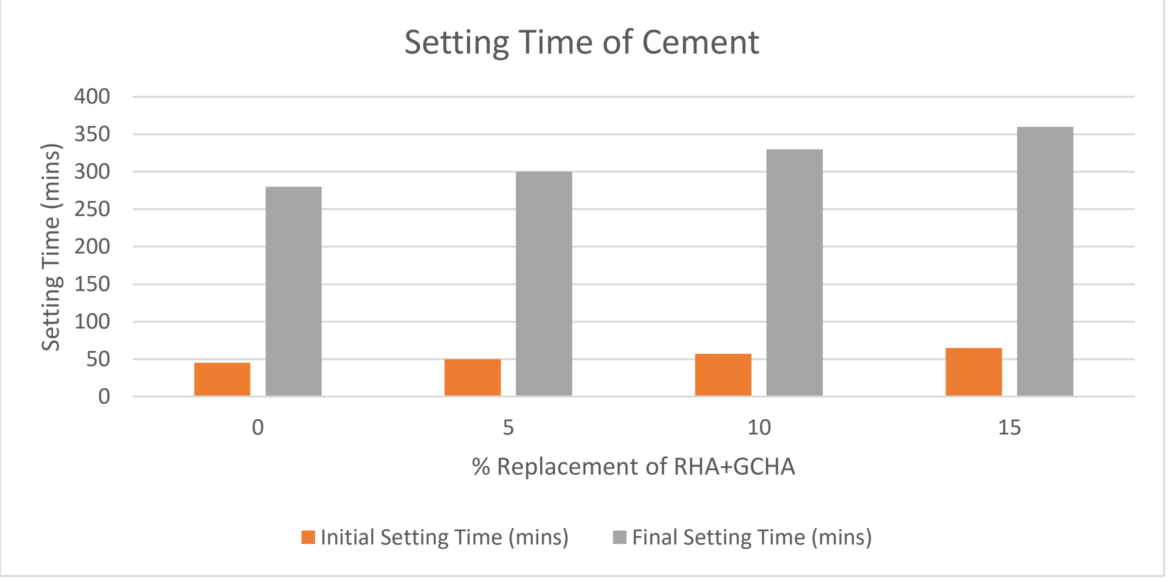

Figure 4.5: Setting Time Against % Replacement of RHA+GCHA

From the results above, it is evident that the replacement of cement with a combined mix of RHA and GCHA leads to a gradual increase in standard consistency, initial setting time, and final setting time. This can be attributed to the slower pozzolanic reaction of the ash materials compared to the hydration of OPC. As the replacement level increased from 0% to 15%, the cement paste required more water and took take to set. These results are in line with findings from previous research. Studies have shown that the incorporation of Rice Husk Ash in cementitious systems leads to increased water demand due to its porous structure and high surface area (Crystals, MDPI, 2021). Similarly, Guinea Corn Husk Ash and related agricultural ashes delay setting time due to their slower pozzolanic activity, as supported by research on Corn Cob Ash and similar agro-waste materials (Scholink, 2022). The study by Zain et al. (2004) on RHA also confirmed the delayed setting and improved later strength development, which corresponds to the trend observed in this investigation. This suggests that while RHA and GCHA improve sustainability by reducing cement usage, adjustments in mix design and curing practices are essential for optimizing performance.

4.2 Compressive Test

Guinea corn husk ash and Rice husk ash was added in increments of 5, 10, and 15% as partial replacement of cement for a high-performance concrete. The strength determined for various ages of curing (7,14, and 28days). The results of the compressive strength tests are shown in the tables below and illustrated in graph by Figure 4.6

Table 4.11: For Control 0% Replacement of GHCA and RHA

Age (days)	**S/N**	**Weight (kg)**	**Density (kg/m)**	**Load (kn)**	**Ultimate Bearing Strength (n/mm)**
7	**A**	**2.379**	**2379**	**252**	**25.2**

7	**B**	**2.381**	**2381**	**256**	**25.6**
Average		**2.380**			**25.4**
14	**A**	**2.616**	**2616**	**264**	**26.4**
14	**B**	**2.354**	**2354**	**248**	**24.8**
Average					**25.6**
28	**A**	**2.414**	**2414**	**336**	**33.6**
28	**B**	**2.393**	**2933**	**300**	**30.0**
Average			**2673.5**		**31.8**

Table 4.12: For 5% Replacement of GHCA and RHA

Age (days)	S/N	Weight (kg)	Density (kg/m)	Load (kn)	Ultimate Bearing Strength (n/mm)
7	**A**	**2.367**	**2367**	**216**	**21.6**
7	**B**	**2.349**	**2349**	**220**	**22.0**
Average		**2.358**			**21.8**
14	**A**	**2.343**	**2343**	**236**	**23.6**
14	**B**	**2.385**	**2385**	**220**	**22.0**
Average		**2.364**			**22.8**
28	**A**	**2.309**	**2309**	**308**	**30.8**
28	**B**	**2.379**	**2379**	**328**	**32.8**

Average			**2344**		**31.8**

Table 4.13: For 10% Replacement of GHCA and RHA

Age (days)	**S/N**	**Weight (kg)**	**Density (kg/m)**	**Load (kn)**	**Ultimate Bearing Strength (n/mm)**
7	**A**	**2.372**	**2372**	**176**	**17.6**
7	**B**	**2.349**	**2349**	**184**	**18.4**
Average		**2.361**			**18.0**
14	**A**	**2.354**	**2354**	**216**	**21.6**
14	**B**	**2.377**	**2377**	**208**	**20.8**
Average		**2.366**			**21.2**

28	**A**	**2.375**	**2375**	**304**	**30.4**
28	**B**	**2.417**	**2417**	**316**	**31.6**
Average			**2396**		**31.0**

Table 4.14: For 15% Replacement of GHCA and RHA

Age (days)	**S/N**	**Weight (kg)**	**Density (kg/m**	**Load (kn)**	**Ultimate Bearing Strength (n/mm)**
7	**A**	**2.265**	**2265**	**168**	**16.8**
7	**B**	**2.301**	**2301**	**164**	**16.4**
Average		**2.283**			**16.6**

14	**A**	**2.280**	**2280**	**188**	**18.8**
14	**B**	**2.339**	**2339**	**196**	**19.6**
Average		**2.310**			**19.2**
28	**A**	**2.289**	**2289**	**252**	**25.2**
28	**B**	**2.322**	**2322**	**220**	**22.0**
Average			**2305.5**		**23.6**

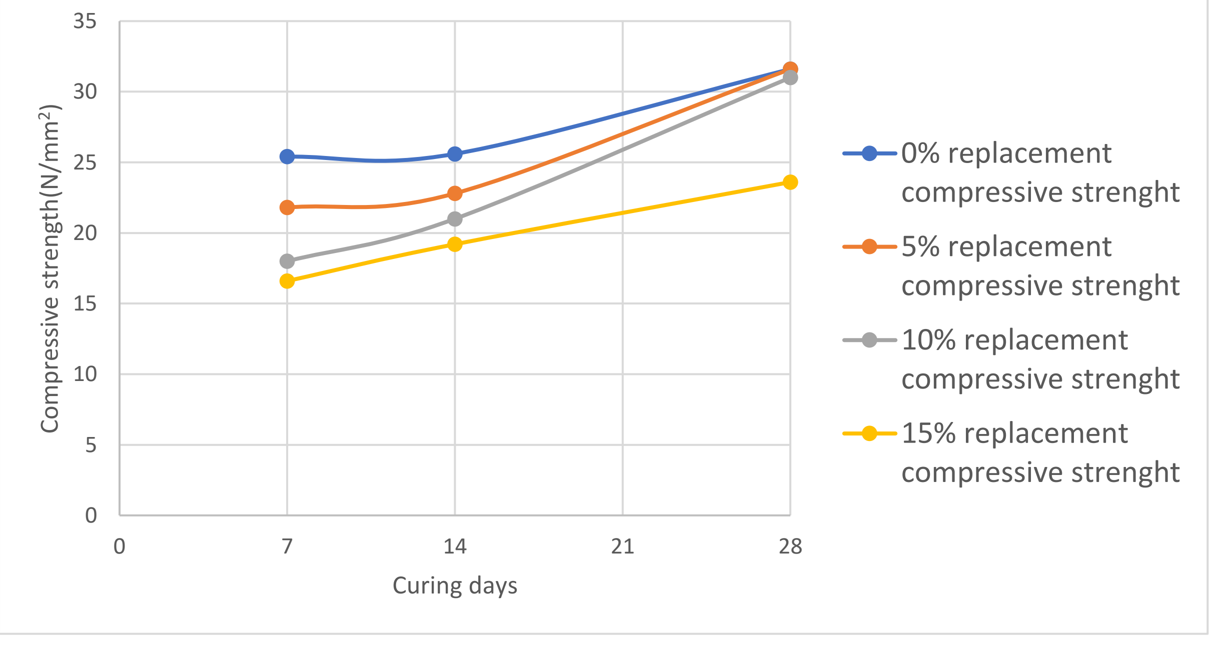

Figure 4.6: Compressive Strength Against Curing Days

The compressive strength behavior of high-performance concrete (HPC) incorporating combined Rice Husk Ash (RHA) and Guinea Corn Husk Ash (GCHA) as partial replacements for ordinary Portland cement was thoroughly examined at varying replacement levels of 5%, 10%, and 15%, and over curing periods of 7, 14, and 28 days. The control mix, which contained no pozzolanic replacement, recorded compressive strengths of 25.4 N/mm^2, 25.6 N/mm^2, and 31.8 N/mm^2 at 7, 14, and 28 days, respectively. When 5% of cement was replaced with a combination of RHA and GCHA, early-age strength decreased slightly to 21.8 N/mm^2 at 7 days and 22.8 N/mm^2 at 14 days, but rose to 31.8 N/mm^2 at 28 days, having same strength with the control. The 10% replacement mix showed a more significant reduction in early-age strength, recording 18.0 N/mm^2 and 21.6 N/mm^2 at 7 and 14 days, respectively. However, this mix achieved a strength close to the control and 5% concrete 28-day strength of 31.0 N/mm^2, representing a notable improvement close to the control mix. At 15% replacement, compressive strength consistently declined across all curing ages, with values of 16.6 N/mm^2, 19.2 N/mm^2, and 23.6 N/mm^2, indicating that excessive ash content may dilute the cementitious matrix and hinder strength development.

These results suggest that a 5% replacement level is optimal, providing the best balance between early and later strength development. This behavior is attributed to the pozzolanic reaction between the amorphous silica in RHA and GCHA and the calcium hydroxide released during cement hydration, forming additional calcium silicate hydrate (C-S-H) gel, which enhances the microstructure and overall strength of the concrete. The delayed strength gain seen in ash-blended mixes is consistent with the characteristics of pozzolanic materials, which typically contribute more significantly to strength at later curing stages.

The outcome corroborates findings from previous studies. For example, Yusuf et al. (2020) and Ganesan et al. (2017) affirmed that rice husk ash, due to its high silica content, improves strength and durability in cementitious systems, especially when well-processed and blended with other reactive ashes. Similarly, Adekunle and Okeniyi (2018) demonstrated the positive synergy achieved through blending agro-waste materials, which enhances the performance.

Furthermore, this study aligns with contemporary sustainability goals. Cement production contributes substantially to global carbon emissions, and partial substitution with agro-waste ash reduces the demand for clinker, thus lowering CO_2 emissions. The integration of RHA and GCHA not only reduces environmental pollution from open-field burning but also converts agricultural waste into value-added construction materials. Oti et al. (2019) noted that using agro-pozzolans in concrete could reduce embodied carbon by up to 30%, depending on dosage and processing.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the methodology results in this project work. The following conclusion are hereby made:

1. The chemical analysis of RHA and GCHA indicates a strong pozzolanic activity as the combined oxides (SiO_2+Al_2O_3+Fe_2O_3) exceeds 70% which is classified as a Class C pozzolan according to ASTM C618.
2. A 5% replacement level of GCHA and RHA replacement demonstrated equivalence to the control in 28-day strength making it the optimum percentage replacement, while a 10% replacement was a bit below the control.
3. The use of RHA and GCHA provides an eco-friendly and cost-effective approach to concrete production, promoting sustainability through waste utilization.

5.2 Recommendations

5.2.1 Recommendation for this Research

1. Concrete practitioners and construction professionals should consider using up to 5% combined RHA and GCHA as partial cement replacements in HPC, especially where these materials are locally available.
2. Additional testing should be conducted to evaluate the performance of the blended ash concrete in aggressive environments such as marine or sulphate-prone areas.
3. It would be beneficial to explore mechanical properties beyond compressive strength, such as flexural strength, splitting tensile strength, and modulus of elasticity.
4. The potential for higher replacement levels beyond 10% should be investigated to determine the threshold for strength reduction.
5. Policy and industry standards could be considered to include guidelines for Agro-waste pozzolans in sustainable concrete practices.

5.2.2 Recommendation for Further Research

1. Durability Studies: Investigate long-term durability characteristics such as permeability, water absorption, acid resistance, and chloride penetration.

2. Microstructural Analysis: Use Scanning Electron Microscopy (SEM) or X-ray Diffraction (XRD) to understand the hydration and pozzolanic interaction between RHA, GCHA, and cement.
3. Life-Cycle Costing and Environmental Impact: Assess the cost-effectiveness and CO_2 savings associated with replacing cement with agro-waste ashes.
4. Field Applications: Test these findings in actual structural elements or site conditions to validate laboratory-scale results.

REFERENCES

Akinwumi, I. I., Adeyemi, O. A., & Bello, A. A. (2019). Utilization of agro-wastes in high performance concrete: Experimental study on guinea corn husk ash. Journal of Cleaner Production, 228, 1232–1244.

Ali, I., & Kwan, A. K. H. (2020). Assessment of coarse aggregate characteristics in West African concrete. International Journal of Civil Engineering and Technology, 11(5), 145–152.

Bakar, B. H. A., Putrajaya, R., & Abdulaziz, H. (2010). Malaysian rice husk ash – Improving the durability and corrosion resistance of concrete: A review. Construction and Building Materials, 25(3), 1205–1211.

Buertey, J., & Ayiah-Mensah, E. (2018). Effect of coarse aggregate gradation on concrete strength. Journal of Building Performance, 9(1), 23–29.

Choudhary, S., Jain, R., & Shrivastava, R. (2014). High performance concrete: A review. International Journal of Engineering Research and Applications, 4(7), 35–42.

Chowdhury, S., Maniar, A., & Suganya, O. (2017). Strength development in concrete with rice husk ash as an additive material. Construction and Building Materials, 146, 464–474.

Elahi, A., Basit, A., & Tariq, A. (2023). Influence of pozzolanic materials on strength and durability of concrete: A comparative study. Materials Today: Proceedings, 66, 2719–2727.

Faseyemi, V. A. (2012). Suitability of agro-waste ash as partial replacement of cement in concrete. International Journal of Civil and Structural Engineering, 2(4), 1041–1048.

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.

Gutiérrez, R. M., Torres, D. G., & Romero, J. M. (2018). Durability performance of concrete with rice husk ash as a supplementary cementitious material. Construction and Building Materials, 176, 688–699.

Habeeb, G. A., & Fayyadh, M. M. (2009). Rice husk ash concrete: The effect of RHA average particle size on mechanical properties and drying shrinkage. Australian Journal of Basic and Applied Sciences, 3(3), 1616–1622.

Kannan, D. M. (2017). High-performance concrete: Strength, durability, and sustainability perspectives. International Journal of Civil Engineering Research, 8(2), 105–114.

Khan, M. I., Siddique, M., & Kundu, S. P. (2020). Pozzolanic activity of agro-waste based concrete. Journal of Cleaner Production, 259, 120749.

Khusbu, B., & Sharma, A. K. (2014). Compressive strength of concrete using RHA. International Journal of Civil and Structural Engineering, 5(1), 91–96.

Mehta, P. K., & Monteiro, P. J. M. (2006). Concrete: Microstructure, properties, and materials (3rd ed.). McGraw-Hill.

Mehta, P. K., & Monteiro, P. J. M. (2014). Concrete: Structure, properties, and materials (4th ed.). McGraw-Hill Education.

Nair, D. G., Fraaij, A. L. A., Klaassen, A. A. K., & Kentgens, A. P. M. (2013). Synergistic effect of RHA and GCHA in pozzolanic concrete. Cement and Concrete Research, 42(6), 872–879.

Ndububa, E. E., & Nurudeen, Y. D. (2015). Sustainable concrete production using agro-waste materials in Nigeria. International Journal of Scientific & Engineering Research, 6(7), 774–780.

Neville, A. M. (2011). Properties of concrete (5th ed.). Pearson Education Limited.

Neville, A. M., & Brooks, J. J. (2010). Concrete Technology (2nd ed.). Pearson Education.

Olutoge, F. A., & Olofinnade, O. M. (2015). Strength performance of HPC containing agro-waste ash. International Journal of Engineering and Advanced Technology, 4(6), 172–177.

Olutoge, F. A., Olalusi, O. B., & Azeez, T. A. (2012). Investigating the performance of HPC with pozzolanic ash. Journal of Engineering Science and Technology, 7(6), 753–764.

Oti, A. H., Okon, A. J., & Ibeh, I. G. (2019). Carbon savings potential of agro-waste-based pozzolans. Journal of Sustainable Construction Materials and Technologies, 4(3), 85–92.

Paya, J., Monzo, J., Borrachero, M. V., & Velazquez, S. (2002). Pozzolanic activity of rice husk ash. Cement and Concrete Research, 32(9), 1525–1531.

Sata, V., Jaturapitakkul, C., & Kiattikomol, K. (2007). Utilization of palm oil fuel ash in high-strength concrete. Cement and Concrete Research, 37(3), 456–462.

Shi, C., Jiménez, A. F., & Palomo, A. (2011). New cements for sustainable development. Cement and Concrete Research, 41(7), 750–763.

Subbulakshmi, S., Ramasamy, V., & Sekar, S. K. (2014). Use of rice husk ash in concrete. Journal of Civil Engineering Research, 4(3A), 1–6.

Yusuf, M. O., Salami, A. W., & Lawal, A. A. (2020). Effect of agro-waste ashes on the strength properties of concrete. International Journal of Engineering Research and Technology, 9(4), 50–57.

Zain, M. F. M., Islam, M. N., & Mahmud, F. (2004). Pozzolanic reaction of rice husk ash cement systems. Construction and Building Materials, 18(8), 575–581.

Zhang, M. H., & Malhotra, V. M. (1996). High-performance concrete incorporating rice husk ash as a supplementary cementing material. ACI Materials Journal, 93(6), 629–636.