UTILIZATION OF PLANTAIN HUSK ASH AND SAW DUST ASH AS A PARTIAL REPLACEMENT FOR CEMENT IN SUSTAINABLE CONCRETE PRODUCTION

BY

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CERTIFICATION

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DEDICATION

This project work is dedicated to my Family for their unwavering support and encouragement throughout this project.

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ABSTRACT

The continuous increase in cement production has raised serious environmental concerns due to its high energy consumption and carbon emissions. At the same time, large quantities of agricultural and wood-processing wastes such as plantain husks and sawdust are generated daily and often disposed of indiscriminately, contributing to environmental pollution. This study investigates the potential use of Plantain Husk Ash (PHA) and Sawdust Ash (SDA) as partial replacements for Ordinary Portland Cement in concrete production as a means of promoting sustainable construction practices.

Concrete was produced using a 1:2:4 mix ratio, with cement partially replaced by a blended combination of PHA and SDA in equal proportions at replacement levels of 5%, 10%, 15%, 20%, and 25% by weight of cement. The workability of the fresh concrete was evaluated using the slump test, while compressive and flexural strength tests were carried out after 7, 14, and 28 days of water curing in accordance with relevant British Standards (BS EN) specifications.

The experimental results indicated that workability decreased progressively with increasing replacement levels due to the higher water absorption characteristics of the ashes. Similarly, compressive and flexural strengths reduced as the percentage of replacement increased. However, concrete mixes containing up to 10–15% replacement achieved satisfactory strength values suitable for non-structural applications and certain light structural uses.

The study concludes that Plantain Husk Ash and Sawdust Ash can be effectively utilized as supplementary cementitious materials in concrete at controlled replacement levels. Their use not only reduces dependence on conventional cement but also provides an environmentally friendly method of managing agro-industrial waste, thereby contributing to sustainable and cost-effective concrete production.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Concrete is an essential construction material utilized globally for its strength, durability, and versatility. It plays a vital role in infrastructure development, ranging from residential buildings to highways, bridges, and dams. At the core of concrete production lies ordinary Portland cement (OPC), which serves as the primary binder. However, the production of OPC is associated with substantial environmental concerns. Notably, the cement industry contributes approximately 7–8% of the total global carbon dioxide (CO_2) emissions due to the calcination of limestone and combustion of fossil fuels during manufacturing, a process that is also highly energy-intensive. Furthermore, the extraction of raw materials such as limestone and clay places pressure on natural resources.

As the demand for construction materials continues to rise in response to rapid urbanization, there is an urgent need to develop sustainable alternatives that reduce the environmental footprint of cement production. One promising strategy involves partially replacing OPC with supplementary cementitious materials (SCMs), particularly those derived from agricultural and industrial waste. This not only helps in waste management but also lowers the cost of construction materials and promotes environmental conservation.

Among the numerous waste materials investigated, plantain husk ash (PHA) and sawdust ash (SDA) have gained attention due to their pozzolanic properties and availability in developing regions. Plantain is widely cultivated across West Africa, Latin America, and parts of Asia. After harvesting, the fibrous outer husk is often discarded as waste. Similarly, sawdust is an abundant by-product of timber industries. When these materials are burned under controlled conditions, they yield ashes rich in amorphous silica, calcium oxide, and alumina, making them suitable for use as partial cement replacements.

Utilizing PHA and SDA in concrete production has the potential to enhance certain properties of concrete, such as workability, durability, and resistance to sulphate attack. Furthermore, their incorporation reduces the volume of cement used, thereby mitigating the environmental and economic impacts associated with cement production.

1.2 Statement of the Problem

The growing concern over the environmental impact of cement manufacturing, coupled with the high cost of construction materials in developing countries, calls for the urgent adoption of sustainable construction practices. OPC production is energy-intensive, emits large quantities of greenhouse gases, and depletes non-renewable resources.

Simultaneously, the improper disposal of agricultural residues such as plantain husks and industrial by-products like sawdust contributes to environmental degradation. In Nigeria alone, it is estimated that over 70 million tonnes of agricultural waste are generated annually, with plantain husks constituting a significant portion of this biomass waste. Similarly, the timber industry produces millions of cubic meters of sawdust waste yearly, often leading to large, unmanaged piles. These wastes are often burnt in open air or dumped in landfills, posing additional environmental hazards such as blocking drainage systems, polluting water bodies, and creating breeding grounds for disease vectors.

Despite the availability of research on alternative materials, studies specifically combining PHA and SDA in concrete are limited. There is a need to investigate the synergy between these ashes when used together as partial cement replacements. This synergy is anticipated due to the complementary chemical compositions and particle size distributions of PHA and SDA, which could lead to improved packing density and enhanced pozzolanic reactions, potentially resulting in superior concrete properties compared to using either ash alone. This study seeks to assess their performance in concrete in terms of strength, durability, and economic feasibility.

This study seeks to address these gaps by evaluating the potential of combining plantain husk ash and sawdust ash as a partial replacement for OPC in the production of sustainable concrete.

1.3 Aim and Objectives of the Study

The aim of the study is to evaluate the performance of concrete produced using plantain husk ash (PHA) and sawdust ash (SDA) as partial replacements for ordinary Portland cement (OPC) in order to promote sustainability and resource efficiency in concrete production.

The objectives are as follows:

1. To determine the physical and chemical properties of PHA and SDA.
2. To assess the setting time of cement blends and workability fresh concrete with varying percentages of PHA and SDA.
3. To evaluate the mechanical properties (compressive strength, split tensile strength, and flexural strength) of concrete containing PHA and SDA.
4. To analyze the durability of the modified concrete, via water absorption, and Chloride penetration test.

5. To conduct an economic cost analysis of concrete incorporating PHA and SDA compared to conventional concrete.

1.4 Significance of the Study

This research holds considerable significance in promoting sustainable construction practices through the utilization of locally available agricultural and industrial wastes. The study aligns with global efforts to reduce CO_2 emissions, manage waste sustainably, and develop low-carbon construction materials.

a. **Environmental Benefit:** By reducing reliance on cement, this study supports efforts to lower carbon emissions and promote a circular economy by transforming waste into useful construction materials.

b. **Economic Benefit:** PHA and SDA are readily available at minimal cost, offering a potential reduction in the cost of concrete, especially in rural or low-income areas.

c. **Technical Advancement:** The study provides valuable data on the mechanical and durability performance of PHA-SDA blended concrete, contributing to engineering knowledge and standards development.

d. **Waste Management:** It offers a practical solution for the sustainable disposal of plantain husks and sawdust, which are otherwise treated as environmental burdens.

1.5 Scope and Limitations of the Study

This study is restricted to the investigation of the performance of concrete incorporating plantain husk ash and sawdust ash as partial replacements for cement. The scope includes:

a. Preparation of PHA and SDA under controlled conditions.

b. Testing of concrete samples for fresh and hardened properties.

c. Analysis of durability characteristics over a 28–90-day curing period.

d. Economic and environmental impact evaluation, specifically a cost analysis based on material procurement for economic impact and a qualitative assessment of environmental benefits (e.g., reduced waste and CO_2 emissions) for environmental impact.

Geographic Focus: The research focuses on materials commonly found in Nigeria and other tropical regions where plantain and timber processing are prevalent.

Limitations:

a. Variability in ash composition based on source and burning conditions, which may influence consistency of results and require careful characterization of each batch.

b. Laboratory-scale analysis may not reflect all field conditions, particularly for large-scale applications.

c. Long-term durability beyond 90 days may not be covered due to time constraints, indicating the need for future studies in this area.

d. Specific replacement ranges will be limited to 0% to 20% for PHA and 0% to 15% for SDA, with total SCM replacement not exceeding 30% of cement by weight.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction to Cement and Concrete

Concrete is the most widely used construction material globally, serving as the backbone for various infrastructures, including buildings, bridges, roads, and dams. Its versatility, strength, and durability make it indispensable in modern construction. At its core, concrete is a composite material primarily composed of a binding agent (cement), aggregates (fine aggregates like sand and coarse aggregates like gravel or crushed stone), and water. The quality and properties of concrete are heavily influenced by the proportion and characteristics of these constituents.

The primary binding agent in conventional concrete is Portland cement. There are several types of Portland cement, classified based on their composition and properties (e.g., Ordinary Portland Cement, Rapid Hardening Cement, Sulphate Resisting Cement). The role of cement is crucial as it chemically reacts with water in a process known as hydration. This exothermic reaction forms a calcium silicate hydrate (C-S-H) gel, along with calcium hydroxide ($Ca(OH)_2$) and other minor hydration products. The C-S-H gel is the main component responsible for the strength and binding properties of concrete, gradually hardening over time to form a solid matrix that binds the aggregates together. The rate and extent of hydration directly impact the concrete's early and long-term strength development, as well as its microstructural characteristics.

2.2 Environmental Impact of Conventional Cement Production

Despite its vital role in development, the production of conventional Portland cement is a highly energy-intensive process with significant environmental implications. The primary raw materials for cement production are limestone and clay, which are extracted through quarrying, leading to habitat destruction and landscape degradation. The most pressing environmental concern, however, is the substantial emission of carbon dioxide (CO_2 Approximately 5% to 8% of global anthropogenic CO_2 emissions are attributed to cement manufacturing. These emissions arise from two main sources: the calcination of limestone (which releases CO_2 as calcium carbonate ($CaCO_3$ converts to calcium oxide (CaO)) and the combustion of fossil fuels used to heat kilns to extremely high temperatures (around 1450°C).

Beyond CO_2 emissions, cement production consumes vast amounts of energy, primarily from coal and petroleum coke, exacerbating fossil fuel depletion and contributing to severe air pollution. Other environmental impacts include the generation of dust and particulate matter, the release of nitrogen oxides (NO_2) and sulfur dioxide (SO_2), and the consumption of large quantities of water. These factors collectively exacerbate climate change, contribute to respiratory illnesses, acid rain, and ecosystem disruption.

Recognizing these profound impacts, there is a global imperative to transition towards more sustainable concrete production methods. Current global efforts are focused on reducing the clinker content in cement by incorporating supplementary cementitious materials (SCMs), optimizing energy efficiency in cement plants, developing novel low-carbon cements, and exploring carbon capture and utilization technologies. The ultimate goal is to reduce the carbon footprint of concrete and make the construction industry more environmentally responsible.

2.3 Supplementary Cementitious Materials (SCMs)

Supplementary Cementitious Materials (SCMs) are finely divided siliceous or alumino-siliceous materials that, in themselves, possess little or no cementitious value but, in the presence of moisture, react chemically with calcium hydroxide ($Ca(OH)_2$) released during cement hydration to form compounds possessing cementitious properties. This reaction is known as the pozzolanic reaction. Additionally, SCMs can act as physical fillers, improving the particle packing density of the concrete matrix.

2.3.1 Classification of SCMS

1. **Natural Pozzolans:** These are naturally occurring materials like volcanic ash and diatomaceous earth that exhibit pozzolanic activity.
2. **Artificial Pozzolans:** These are by-products from industrial processes or agricultural activities that possess pozzolanic or latent hydraulic properties. Latent hydraulic materials, like Ground Granulated Blast Furnace Slag (GGBS), possess inherent cementitious properties that are activated in the presence of calcium hydroxide. Examples include fly ash, silica fume, ground granulated blast furnace slag (GGBS), metakaolin, rice husk ash, and indeed, plantain husk ash and sawdust ash.

a. **Fly Ash:** A by-product of coal combustion in thermal power plants, known for its spherical particle shape and pozzolanic activity. It improves workability, long-term strength, and durability.

b. **Silica Fume:** An amorphous silicon dioxide by-product of silicon or ferrosilicon alloy production. It is extremely fine and highly reactive, significantly enhancing strength, impermeability, and abrasion resistance.

c. **Ground Granulated Blast Furnace Slag (GGBS):** A glassy, granular material formed when molten iron blast furnace slag is rapidly quenched. It exhibits latent hydraulic properties and improves durability, particularly against sulphate attack.

Mechanisms of Improvement by SCMs:

1. **Pozzolanic Reaction:** SCMs, rich in amorphous silica (SiO_2) and alumina (Al_2O_3), react with the calcium hydroxide ($Ca(OH)_2$) generated during the hydration of Portland cement. This reaction consumes the $Ca(OH)_2$ (which offers little strength to the concrete) and produces additional C-S-H gel. The formation of more C-S-H gel leads to increased strength, reduced permeability, and enhanced durability of the concrete.
2. **Filler Effect:** The fine particles of SCMs fill the voids between cement particles and aggregates, leading to a denser and more homogeneous concrete microstructure. This physical packing effect reduces porosity, improves the interfacial transition zone between aggregate and paste, and contributes to increased strength and impermeability.

2.4 Plantain Husk Ash (PHA) as an SCM

Plantain (Musa paradisiaca) is a staple food crop in many tropical and subtropical regions, particularly across Africa, Latin America, and Asia. In Nigeria and other West African nations, its cultivation generates a substantial amount of agricultural waste, primarily the plantain husk, which constitutes about 30-40% of the fruit's total weight. This husk is often discarded, leading to disposal challenges and environmental pollution if not managed properly. The potential of plantain husk as a sustainable raw material for producing supplementary cementitious material, Plantain Husk Ash (PHA), has gained increasing attention due to its rich silica content.

Previous studies have investigated the chemical composition of PHA, consistently reporting high percentages of silicon dioxide (SiO_2), often exceeding 60-70%, alongside varying amounts of potassium oxide (K_2O),calciumoxide (CaO),aluminumoxide (Al_2O_3), and iron oxide (Fe_2O_3). For a material to be considered pozzolanic according to ASTM C618, the combined sum of SiO_2,

Al_2O_3, and Fe_2O_3 must be at least 70%. Many studies have demonstrated that appropriately calcined PHA meets this criterion, confirming its pozzolanic potential. The amorphous nature of the silica, achieved through controlled burning temperatures, is crucial for its reactivity. Research by Oyeleke et al. (2021) and Ajibola and Adeyemi (2022) further supports PHA's pozzolanic activity and its suitability for concrete applications. The optimal calcination temperature for PHA typically ranges from 600°C to 800°C, ensuring the silica remains in its reactive amorphous form.

The effect of PHA on the fresh and hardened properties of concrete

1. **Workability:** Generally, incorporating PHA into concrete mixes tends to decrease workability (increase water demand) due to its high specific surface area and irregular particle shape. However, recent studies, such as Sabo et al. (2020), suggest that finely ground PHA can have a filler effect, improving workability at lower replacement levels. The use of superplasticizers is often recommended to maintain desired slump values.
2. **Compressive Strength:** At optimal replacement percentages (typically ranging from 5% to 15%), PHA has been shown to improve the long-term compressive strength of concrete. This is attributed to the pozzolanic reaction, which consumes free $Ca(OH)_2$ and produces additional C-S-H gel, leading to a denser and stronger microstructure. Early-age strength might be slightly lower compared to the control mix due to slower pozzolanic activity. Research by Ayanda et al. (2023) indicates promising strength development up to 90 days with PHA inclusion.
3. **Tensile and Flexural Strength:** Similar to compressive strength, the splitting tensile and flexural strengths of concrete can be enhanced with optimal PHA incorporation, reflecting the improved bond and reduced porosity of the cement matrix (Okoli and Oparaugo, 2021).

4. **Durability:** Studies have indicated that PHA can enhance the durability of concrete by reducing permeability, improving resistance to sulphate attack, and decreasing water absorption. The refinement of pore structure due to the pozzolanic reaction makes the concrete less susceptible to aggressive environments (Abdulahi et al., 2022). Despite promising results, there are gaps and inconsistencies in existing research on PHA. These include:

a. Variations in the optimal calcination temperature and duration for producing highly reactive PHA, often depending on the plantain variety and burning method.

b. Limited long-term performance data (beyond 90 days) on concrete containing PHA.

c. Insufficient research on the combined effect of PHA with other SCMs, especially other agricultural wastes.

d. Lack of standardized methods for PHA production and quality control, making comparisons across studies challenging.

e. Variability in the chemical composition of plantain husk itself depending on geographical location, soil type, and plant variety.

2.5 Sawdust Ash (SDA) as an SCM

Sawdust, a fine particulate by-product generated from the milling and processing of timber, represents another significant source of lignocellulosic waste globally. In Nigeria, where timber processing is a major industry, sawdust generation is substantial, posing significant environmental challenges, including landfill space consumption and potential for spontaneous combustion or slow decomposition leading to methane emissions. The incineration of sawdust, when controlled, can yield Sawdust Ash (SDA), which has been identified as a potential supplementary cementitious material due to its siliceous nature.

The chemical composition of SDA, like other biomass ashes, is highly dependent on the type of wood, burning temperature, and burning conditions. However, many studies have reported that SDA contains a substantial amount of silicon dioxide (SiO_2), along with varying proportions of potassium oxide (K_2O),calciumoxide(CaO),and aluminumoxide(Al_2O_3). For SDA to exhibit significant pozzolanic activity, the SiO_2 should be in amorphous form, which is best achieved through controlled calcination at temperatures typically between 600°C and 750°C (Alabadan et al., 2018; Obianyo et al., 2020). If the burning temperature is too high, the silica may crystallize, reducing its reactivity.

The effects of SDA on the fresh and hardened properties of concrete

1. **Workability:** Similar to PHA, SDA generally tends to reduce the workability of fresh concrete, requiring higher water content or the use of superplasticizers to achieve a desirable slump. This is primarily due to its high surface area and porous nature (Ettu et al., 2019).
2. **Compressive Strength:** The incorporation of SDA, particularly at moderate replacement levels (e.g., 5-15%), can contribute to the long-term compressive strength of concrete. The pozzolanic reaction of amorphous silica in SDA with $Ca(OH)_2$ enhances the formation of C-S-H gel, leading to densification of the concrete matrix and strength gain over time. However, excessive replacement levels can lead to a reduction in strength due to insufficient cement content for adequate early hydration or dilution effects (Jimoh and Adejoh, 2021).
3. **Tensile and Flexural Strength:** Improvements in splitting tensile and flexural strengths have also been reported with optimized SDA content, attributed to the refined microstructure and enhanced bonding within the concrete (Adewuyi and Aderiye, 2020).

4. **Durability:** SDA has shown potential to improve the durability characteristics of concrete, including reduced water absorption, lower permeability, and enhanced resistance to chemical attacks, due to the pore-filling and pozzolanic effects that lead to a denser and less permeable matrix (Ajibade et al., 2022). Despite these findings, research on SDA as an SCM also faces gaps and inconsistencies:

a. The variability in the chemical and physical properties of SDA depending on the wood species and burning conditions makes it challenging to achieve consistent performance.

b. The optimal calcination temperature and duration for different types of sawdust require more detailed investigation to ensure maximum pozzolanic reactivity.

c. Limited studies focus on the combined use of SDA with other agricultural or industrial wastes.

d. The economic feasibility and practical implementation of collecting, processing, and utilizing large quantities of SDA on a commercial scale need further assessment.

2.5.1 Comparative Chemical Composition of PHA and SDA

While both PHA and SDA are considered pozzolanic, their precise chemical compositions can vary significantly based on source, processing, and burning conditions. A comparative overview from literature highlights their key constituents:

Oxide	**Typical Range in PHA (wt%)**	**Typical Range in SDA (wt%)**
SiO_2	60 – 75	50 – 65
Al_2O_3	2 – 5	1 – 4
Fe_2O_3	0.5 – 2	0.5 – 2
CaO	5 – 10	10 – 20

K_2O	5 – 15	2 – 8
Others (MgO, P_2O_5, Na_2O, etc.)	Balance	Balance

Source: Adapted from various literature ([Oyeleke et al., 2021, Alabadan et al., 2018])

Note: These ranges are illustrative and can vary based on specific biomass source, geographic location, and burning conditions. The high SiO_2 content in both ashes confirms their potential for pozzolanic activity, while variations in other oxides like K_2O and CaO might influence workability and hydration kinetics.

2.6 Combined Utilization of Agricultural and Industrial Wastes in Concrete

The concept of utilizing multiple supplementary cementitious materials (SCMs) in concrete, often referred to as blended cements or ternary/quaternary blends, has gained prominence. This approach aims to leverage the synergistic benefits that different SCMs can offer, potentially leading to superior concrete properties and further reducing reliance on Portland cement. When combining agricultural and industrial wastes, the objective is often to optimize the particle packing density and maximize the pozzolanic reaction through complementary chemical compositions and particle sizes.

Review of Studies on the Combined Use of Supplementary Cementitious Materials (SCMs)

1. **Fly Ash and Rice Husk Ash:** Research by Thomas et al. (2019) demonstrated that a combination of fly ash and rice husk ash can lead to improved long-term strength and durability in concrete, with the finer rice husk ash enhancing the pozzolanic activity of the coarser fly ash.

2. **Metakaolin and Ground Granulated Blast Furnace Slag:** Studies by Gopi et al. (2020) indicated that binary blends of metakaolin and GGBS can significantly reduce permeability and enhance resistance to chloride ingress, showcasing a beneficial interaction between a highly reactive pozzolan and a latent hydraulic material.
3. **Bagasse Ash and Silica Fume:** Suresh et al. (2021) found that combining bagasse ash with a small percentage of silica fume resulted in concrete with improved compressive strength and reduced water absorption, highlighting how a less reactive SCM can benefit from the presence of a highly reactive one.

Rationale for the Combined Utilization of Supplementary Cementitious Materials

The strategic combination of different supplementary cementitious materials (SCMs), such as plantain husk ash (PHA) and sawdust ash (SDA), offers several technical, environmental, and economic advantages. This approach, often referred to as blended or composite SCM utilization, is based on the principle that two or more SCMs may interact synergistically to enhance concrete performance beyond the capabilities of individual components. The key motivations for employing a combined utilization strategy include:

1. **Complementary Chemical Reactivity:** Different SCMs often possess varied chemical compositions. When blended, one material may provide early-age reactivity while another contributes to long-term strength and durability. For instance, an SCM rich in amorphous silica may react rapidly, while another with a slower pozzolanic profile may extend the hydration process over time, improving performance holistically.
2. **Optimized Particle Packing and Microstructure Densification:** The use of SCMs with diverse particle size distributions improves the packing density of the concrete matrix.

Finer particles can fill microvoids between larger cement grains and aggregates, reducing porosity, enhancing cohesiveness, and promoting a refined pore structure.

3. **Enhanced Durability:** Blending SCMs can lead to a more resistant concrete matrix against environmental aggressors such as chloride ions, sulphates, and carbonation. This increased resilience is a result of the refined microstructure and the additional formation of secondary hydration products, such as calcium silicate hydrate (C-S-H) gels.
4. **Improved Workability and Rheological Properties:** When properly proportioned, certain combinations of SCMs can enhance the flow characteristics of fresh concrete, reduce segregation, and lower the need for chemical admixtures. This is particularly beneficial in mixes that might otherwise suffer from reduced slump due to high surface area ashes.
5. **Resource Efficiency and Waste Minimization:** Utilizing multiple waste-derived SCMs simultaneously maximizes the recycling of agricultural and industrial by-products, reducing the burden on landfills and conserving natural resources. It also aligns with circular economy principles and promotes sustainability in the construction sector.
6. **Economic Feasibility:** The combined use of locally available waste materials may reduce the overall cost of concrete production. By minimizing dependence on imported or high-cost cement, construction activities become more affordable and accessible, particularly in developing regions.

Objectives of Research on Combined Utilization of SCMs

Synergistic Effects: Where the combined performance of SCMs is greater than the sum of their individual contributions. This could manifest as enhanced strength development, improved workability, or superior durability properties compared to mixes containing only one SCM. Such synergy often arises from optimized particle packing and a more efficient pozzolanic reaction due to a broader range of reactive components or improved distribution of hydration products.

Antagonistic Effects: Less commonly, combining SCMs might lead to antagonistic effects, where the performance is worse than expected. This could be due to incompatibilities in chemical reactions, excessive water demand, or dilution effects if the combined replacement percentage is too high without adequate reactivity from the SCMs.

Reviewing such studies is crucial to understanding the potential interactions between PHA and SDA when used together. It helps in formulating mix designs that capitalize on their strengths and mitigate any potential weaknesses, ultimately leading to more optimized and sustainable concrete formulations.

2.7 Theoretical Framework

The theoretical foundation for utilizing plantain husk ash (PHA) and sawdust ash (SDA) as partial replacements for cement in concrete production primarily rests on two fundamental principles: the pozzolanic reaction and the filler effect.

Pozzolanic Reaction

The pozzolanic reaction is a crucial chemical process that occurs when a pozzolanic material (like PHA or SDA) is introduced into a Portland cement concrete mix. During the hydration of Portland cement, calcium hydroxide ($Ca(OH)_2$), also known as portlandite, is liberated as a by-product. While $Ca(OH)_2$ contributes to early strength, it is relatively soluble and can be susceptible to aggressive chemical attacks, making the concrete less durable in the long term.

Pozzolanic materials, such as PHA and SDA, contain amorphous (non-crystalline) silicon dioxide (SiO_2 and, to a lesser extent, aluminum oxide (Al_2O_3). In the presence of moisture, these amorphous silica and alumina react with the free calcium hydroxide ($Ca(OH)_2$) to form additional calcium silicate hydrate (C-S-H) gel and calcium aluminate hydrate (C-A-H) phases.

Secondary formation of C-S-H gel on concrete properties:

Enhanced Strength: The C-S-H gel is the main binding phase in concrete. The formation of additional C-S-H gel densifies the cement matrix, leading to increased long-term compressive, tensile, and flexural strengths.

Reduced Permeability: By consuming the $Ca(OH)_2$ and filling capillary pores with new C-S-H gel, the pozzolanic reaction refines the pore structure, making the concrete less permeable to water and aggressive ions (e.g., chlorides, sulphates).

Improved Durability: Lower permeability translates to enhanced resistance against various forms of deterioration, such as sulphate attack, chloride ingress, and carbonation, thereby extending the service life of the concrete structure.

Reduced Leaching: The consumption of $Ca(OH)_2$ also reduces its potential for leaching out of the concrete, which can contribute to efflorescence and strength degradation over time.

For PHA and SDA to be effective pozzolans, it is essential that their silica content is predominantly in the amorphous state, which is achieved through controlled thermal treatment (calcination) at their respective optimal temperatures (600-800°C for PHA and 600-750°C for SDA). Over-burning can lead to the crystallization of silica, making it less reactive.

Filler Effect

The filler effect, also known as the physical effect or particle packing effect, is another important mechanism through which finely ground SCMs, including PHA and SDA, improve concrete properties. Even if an SCM has low pozzolanic reactivity, its fine particulate nature can significantly contribute to the concrete's performance.

When fine ash particles are introduced into a concrete mix, they physically fill the interstitial voids between the larger cement particles and aggregates. This leads to:

Increased Particle Packing Density: By occupying the empty spaces, the overall packing density of the solid constituents in the concrete paste is improved. A denser packing results in a more homogeneous and compact microstructure.

Reduced Porosity: The filling of voids directly translates to a reduction in the total pore volume and a refinement of the pore size distribution within the concrete matrix. This results in fewer and smaller pores.

Improved Workability (at optimal fineness): While high surface area can increase water demand, very fine particles can sometimes act as internal lubricants, improving the flow characteristics of fresh concrete at certain replacement levels, especially when combined with water-reducing admixtures.

Enhanced Interfacial Transition Zone (ITZ): The ITZ is a thin zone between the cement paste and the aggregate surface, often characterized by higher porosity and a higher concentration of $Ca(OH)_2$ crystals, making it the weakest link in the concrete. Fine SCM particles can migrate into the ITZ, densifying it, reducing the amount of oriented $Ca(OH)_2$ crystals, and improving the bond between the paste and the aggregates. This enhanced ITZ contributes significantly to the overall strength and durability of the concrete.

Both the pozzolanic reaction and the filler effect work synergistically to enhance the fresh and hardened properties of concrete containing PHA and SDA, contributing to the development of sustainable and high-performance concrete. The optimal percentage for combined replacement of PHA and SDA with cement is highly dependent on the specific properties of the ashes and the desired concrete characteristics. The literature often discusses the synergistic effects of such combinations, but a singular, universally recommended percentage range is not explicitly stated as it typically needs to be determined through experimental optimization within a study, balancing the individual contributions and interactions of both SCMs.

CHAPTER THREE

METHODOLOGY

3.1 Materials

The following materials will be utilized for the experimental program:

1. **Ordinary Portland Cement (OPC):** Type I Portland cement, conforming to the specifications of ASTM C150 (Standard Specification for Portland Cement) or EN 197-1 (Cement – Part 1: Composition, specifications and conformity criteria for common cements), will serve as the primary binder.
2. **Aggregates:**

a. **Fine Aggregate:** Locally sourced river sand, free from deleterious materials, will be used. Its properties will conform to ASTM C33 (Standard Specification for Concrete Aggregates) or an equivalent standard. A comprehensive sieve analysis will be performed to determine its particle size distribution.

b. **Coarse Aggregate:** Locally sourced crushed granite (or similar suitable aggregate), conforming to ASTM C33 or equivalent, will be employed. Sieve analysis will be conducted to ascertain its particle size distribution, alongside determination of its specific gravity and water absorption capacity.

3. **Water:** Potable tap water, free from impurities and suitable for concrete mixing, will be used throughout the experimental work.
4. **Plantain Husk:** Raw plantain husks will be obtained from local markets or agricultural waste streams within Nigeria, ensuring a consistent source for the duration of the study.

5. **Sawdust:** Sawdust will be procured from local timber processing mills. The specific wood type (e.g., hardwood, softwood) will be identified and recorded to account for potential variations in ash composition.

6. **Superplasticizer:** A polycarboxylate-based superplasticizer, conforming to ASTM C494 Type F (Standard Specification for Chemical Admixtures for Concrete), will be incorporated into the mixes. This admixture is crucial for maintaining the desired workability and slump, especially with higher SCM content, by reducing the water demand.

3.2 Preparation of Supplementary Cementitious Materials (SCMs)

The plantain husk ash (PHA) and sawdust ash (SDA) will be prepared under controlled conditions to ensure optimal pozzolanic reactivity.

1. **Plantain Husk Ash (PHA):**

a. **Washing and Drying:** Raw plantain husks will be thoroughly washed with potable water to remove any adhering soil, dirt, or organic impurities. Subsequently, the cleaned husks will be sun-dried for a preliminary period, followed by oven-drying at 105°C for 24 hours to ensure complete moisture removal.

b. **Calcination:** The dried plantain husks will be incinerated in a controlled muffle furnace. Based on established literature (e.g., [cite relevant PHA calcination studies from your Chapter 2]), a specific temperature range of 600°C - 700°C will be maintained for a determined duration of 2 hours. This temperature range is critical for ensuring the transformation of silica into its amorphous, highly reactive form, while avoiding crystallization that would reduce pozzolanic activity.

c. **Grinding:** The resulting PHA will be ground using a ball mill or similar high-energy grinding equipment. The grinding process will continue until the ash achieves a desired fineness, typically characterized by passing through a 75 µm (No. 200) sieve, or by achieving a specific surface area determined through the Blaine fineness test (ASTM C204).

2. **Sawdust Ash (SDA):**

a. **Washing and Drying:** Similar to PHA, raw sawdust will be washed to remove impurities and then dried, either by sun-drying followed by oven-drying at 105°C for 24 hours, or by direct oven-drying.

b. **Calcination:** The dried sawdust will be incinerated in a controlled muffle furnace. Drawing from literature on optimal SDA calcination (e.g., [cite relevant SDA calcination studies from your Chapter 2]), a temperature range of 500°C - 600°C will be maintained for a duration of 2 hours. This range is selected to ensure the formation of amorphous silica, which is paramount for its pozzolanic reactivity, while preventing the formation of crystalline phases.

c. **Grinding:** The incinerated SDA will be ground to a fineness comparable to that of PHA, either by passing a 75 µm sieve or by achieving a similar Blaine fineness.

3.3 Characterization of Materials

A comprehensive characterization of all constituent materials will be performed to understand their properties and confirm their suitability for concrete production.

1. **Ordinary Portland Cement (OPC):**

a. Specific Gravity (ASTM C188: Standard Test Method for Density of Hydraulic Cement).

b. Standard Consistency (ASTM C187: Standard Test Method for Amount of Water Required for Normal Consistency of Hydraulic Cement).

c. Setting Times (Initial and Final) (ASTM C191: Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle).

2. **Plantain Husk Ash (PHA) and Sawdust Ash (SDA):**

a. **Chemical Composition:** X-ray Fluorescence (XRF) spectroscopy will be employed to determine the major oxide compositions, including Silicon Dioxide (SiO_2), Aluminum Oxide (Al_2O_2), Iron Oxide (Fe_2O_3), Calcium Oxide (CaO), Potassium Oxide (K_2O), Sodium Oxide(Na_2O), Magnesium Oxide(MgO), and Sulfur Trioxide(SO_2). This analysis is critical for confirming the pozzolanic potential, specifically verifying that the combined sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ exceeds 70% as per ASTM C618 (Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete).

b. **Physical Properties:**

i. Specific Gravity (ASTM C188).

ii. Particle Size Distribution: Determined using a Laser Diffraction Particle Size Analyzer to provide a precise distribution of particle sizes. For coarser particles, sieve analysis will also be performed.

iii. Blaine Fineness (ASTM C204: Standard Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus), to quantify the specific surface area.

iv. Loss on Ignition (LOI) (ASTM C114: Standard Test Methods for Chemical Analysis of Hydraulic Cement), to determine the amount of unburnt carbonaceous material.

v. **Amorphous Nature:** X-ray Diffraction (XRD) will be conducted to confirm the presence and quantify the degree of amorphous silica within the ashes, which is directly correlated with their pozzolanic reactivity.

3.4 Mix Design and Specimen Preparation

The concrete mix designs will be developed to allow for a systematic evaluation of PHA and SDA as partial cement replacements.

Table 3.1: Concrete Mix Proportions (per cubic meter of concrete)

Mix ID	Cement (kg)	PHA (kg)	SDA (kg)	Total Binder (kg)	Water (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Superplasticizer (kg)	W/B Ratio
Control (0% SCM)	350	0	0	350	175	700	1050	3.5	0.50
Individual SCM Mixes (10% Replacement)									
10% PHA Only (10P)	315	35	0	350	175	700	1050	3.5	0.50
10% SDA Only (10S)	315	0	35	350	175	700	1050	3.5	0.50
Blended SCM Mixes									
10% Total SCM (5P5S)	315	17.5	17.5	350	175	700	1050	3.5	0.50
15% Total SCM (7.5P7.5S)	297.5	26.25	26.25	350	175	700	1050	3.5	0.50
20% Total SCM (10P10S)	280	35	35	350	175	700	1050	3.5	0.50
20% Total SCM (12.5P7.5S)	280	43.75	26.25	350	175	700	1050	3.5	0.50
20% Total SCM (7.5P12.5S)	280	26.25	43.75	350	175	700	1050	3.5	0.50

Note: The proportions presented are illustrative and based on an initial W/B ratio of 0.5 and a total binder content of 350 kg/m^3*. Actual quantities and superplasticizer dosage may be adjusted during preliminary trial mixes to achieve the desired workability and performance characteristics for the specific materials used.*

3. **Control Mix:** A control concrete mix (100% OPC) will be designed using a standard method such as ACI 211.1 (Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete) or a relevant British Standard method. The mix will target a specific compressive strength (e.g., 25 MPa or 30 MPa) at 28 days. The water-to-cement (w/c) ratio will be precisely determined and maintained for the control mix.

4. **PHA-SDA Blended Mixes:** OPC will be partially replaced by PHA and SDA at varying percentages. The total SCM replacement will be kept constant across several mixes (e.g., 10%, 15%, 20% by weight of cement), while the ratio of PHA to SDA within that total will be varied. This approach allows for the investigation of synergistic effects.

Example Replacement Levels (Total SCM replacement by weight of cement):

1. **Control:** 0% PHA, 0% SDA

2. **Individual SCM Mixes (for comparison):**

   10% PHA only (0% SDA)

   10% SDA only (0% PHA)

3. **Blended SCM Mixes:**

a. **10% Total SCM:**

   Mix A1: 5% PHA, 5% SDA

b. **15% Total SCM:**

   Mix B1: 7.5% PHA, 7.5% SDA

c. **20% Total SCM:**

   Mix C1: 10% PHA, 10% SDA

   Mix C2: 12.5% PHA, 7.5% SDA

   Mix C3: 7.5% PHA, 12.5% SDA

4. **Mixing Procedure:** Concrete will be mixed in a standard laboratory concrete mixer following established procedures, such as those outlined in ASTM C192 (Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory).
5. **Casting:** Concrete specimens, including cubes (e.g., 150x150x150 mm), cylinders (e.g., 100x200 mm), and prisms (e.g., 100x100x500 mm), will be cast in accordance with relevant standards (e.g., ASTM C31 for cubes/cylinders, ASTM C116 for prisms). Molds will be properly oiled before casting.
6. **Curing:** All cast specimens will be demolded after 24 hours and then immediately transferred to a water curing tank. They will be continuously cured in water at a standard laboratory temperature (e.g., 23 ± 2°C) until the designated time of testing.

3.5 Testing of Fresh Concrete Properties

The following tests will be conducted on fresh concrete immediately after mixing to assess its workability and other properties:

1. **Slump Test:** To evaluate the workability and consistency of the fresh concrete (ASTM C143: Standard Test Method for Slump of Hydraulic-Cement Concrete).
2. **Compacting Factor Test:** This test will be performed, particularly for mixes with lower workability, to provide an alternative measure of compaction (BS 1881-103: Methods for determination of compacting factor).
3. **Setting Time:** The initial and final setting times will be determined using the Vicat apparatus on cement paste specimens prepared with the same SCM percentages as the concrete mixes (ASTM C191).

4. **Density:** The fresh density of the concrete will be determined (ASTM C138: Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete).

5. **Air Content:** The air content of the fresh concrete will be measured using the pressure method (ASTM C231: Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method) or the volumetric method (ASTM C173: Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method).

3.6 Testing of Hardened Concrete Properties

The mechanical properties of the hardened concrete specimens will be evaluated at various curing ages. For each test and curing age, a minimum of three specimens will be tested, and the average value will be reported.

1. **Compressive Strength:**

   Tests will be conducted on cube or cylinder specimens at 3, 7, 28, 56, and 90 days of curing (ASTM C39: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens).

2. **Split Tensile Strength:**

   Tests will be conducted on cylinder specimens at 28 and 90 days of curing (ASTM C496: Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens).

3. **Flexural Strength:**

   Tests will be conducted on prism specimens at 28 and 90 days of curing using the three-point or four-point loading method (ASTM C293: Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading) or ASTM C78:

Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)).

3.7 Durability Studies

The long-term performance and resistance of the modified concrete to aggressive environments will be assessed through the following durability tests:

1. **Water Absorption:**

   Tests will be conducted on oven-dried specimens (e.g., cubes) at 28 and 90 days of curing (ASTM C642: Standard Test Method for Density, Absorption, and Voids in Hardened Concrete). The percentage water absorption will be calculated based on the difference between saturated surface-dry weight and oven-dry weight.

2. **Sulphate Resistance:**

   Concrete specimens (e.g., cubes or prisms) will be immersed in a 5% sodium sulphate (Na_2SO_4) solution after an initial 28-day water curing period. A control group of identical specimens will be continuously immersed in plain water. Mass change, visual inspection for signs of deterioration (cracking, spalling), and residual compressive strength will be monitored at regular intervals (e.g., 56 and 90 days). The sulphate solution will be replenished periodically to maintain concentration.

3. **Resistance to Carbonation:**

   An accelerated carbonation test will be performed. After 28 days of initial water curing, concrete specimens will be exposed to a controlled environment with a high CO_2 concentration (e.g., 5% CO_2) at a controlled relative humidity (e.g., 60-70% RH) and temperature (e.g., 20°C). At designated ages (e.g., 56 and 90 days), specimens will be split, and a 1% phenolphthalein indicator solution will be sprayed on the freshly fractured surface to measure the carbonation depth. The uncarbonated portion will turn pink, while the carbonated portion remains colorless.

3.8 Microstructural Analysis

Advanced microstructural analysis techniques will be employed to gain deeper insights into the internal structure and hydration products of the concrete.

1. **Scanning Electron Microscopy (SEM):** SEM will be used to examine the microstructure of the cement matrix, observe the distribution and morphology of SCM particles, and assess the quality and densification of the interfacial transition zone (ITZ) between the paste and aggregates. This will provide visual evidence of the pozzolanic reaction and filler effect.
2. **X-ray Diffraction (XRD):** XRD will be performed on powdered samples of hardened concrete to identify and quantify the crystalline phases present. This is particularly useful for monitoring the consumption of calcium hydroxide ($Ca(OH)2$) by the pozzolanic reaction and the formation of additional C-S-H and other hydration products over time.

3.9 Economic and Environmental Impact Evaluation

The study will include an assessment of the economic and environmental benefits associated with using PHA and SDA in concrete production.

1. **Economic Benefit:** A comparative cost analysis will be performed. This will involve calculating the material cost per cubic meter of concrete for the control mix and the optimized PHA-SDA blended mixes. The analysis will consider the market cost of OPC, aggregates, and water, juxtaposed with the relatively low or negligible cost of procuring and processing PHA and SDA as waste-derived materials.

2. **Environmental Benefit:** A simplified Life Cycle Assessment (LCA) approach will be adopted, focusing specifically on the embodied CO_2 emissions. This evaluation will quantify the reduction in CO_2 emissions per cubic meter of concrete achieved through the partial replacement of OPC with waste-derived SCMs, highlighting the positive environmental impact of waste valorization.

3.10 Data Analysis

Experimental data will be analyzed using appropriate statistical methods (e.g., ANOVA) to determine the significance of the replacement percentages on concrete properties. Graphs and tables will be used for data presentation. Relationships between different properties (e.g., SCM content vs. strength, porosity vs. durability) will be explored.

CHAPTER FOUR

ANALYSIS AND DISCUSSION OF RESULTS

4.0 Introduction

The results of the chemical analysis of the Plantain Husk Ash and Saw Dust Ash are presented in the chapter with their respective percentage composition. Also presented here include the results from the various test conducted on the aggregates (fine and coarse) which include: sieve analysis and specific gravity test. It involved casting concrete cubes and beams with dimensions 100x100x100mm and 500x100x100mm respectively, with replacement by weight at 5%, 10%, 15%, 20% and 25% a set of control (0% replacement, hence plain concrete), these structural elements were then cured for a period of 7, 14, and 28 days after which the specimens were weighed and the weights were recorded. The concrete specimens were then subjected to compression and bending forces at which the failure loads were obtained and recorded in the tables shown below.

4.1 Results on Chemical Test on Plantain Husk Ash and Saw Dust Ash

The chemical composition of supplementary cementitious materials (SCMs) is one of the major parameters used to assess their pozzolanic activity and suitability as a partial replacement for cement. To determine the potential of Plantain Husk Ash (PHA) and Sawdust Ash (SDA) as SCMs, chemical tests such as X-ray fluorescence (XRF) analysis are typically carried out to identify the oxides present and their respective proportions.

These oxides—mainly silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), and **ferric oxide (Fe_2O_3)**—are indicators of pozzolanic properties, while compounds such as calcium oxide (CaO), magnesium oxide (MgO), and sodium/potassium oxides (Na_2O, K_2O) influence reactivity and stability.

Table 4.1 Showing Typical XRF results for Plantain Husk Ash (PHA)

Chemical Composition of Plantain Husk Ash (PHA)

Oxide	Typical Percentage (%)
Silicon Dioxide (SiO_2)	16.45%
Aluminum Oxide (Al_2O_3)	5.21%
Ferric Oxide (Fe_2O_3)	6.61%
Calcium Oxide (CaO)	15.37%
Magnesium Oxide (MgO)	2.53%
Potassium Oxide (K_2O)	4.92%
Sodium Oxide (Na_2O)	1.24%
Loss on Ignition (LOI)	9.11%
Sulphur Trioxide (SO_3)	1.48%
Total ($SiO_2 + Al_2O_3 + Fe_2O_3$)	28.27%

Table 4.2 Showing Typical XRF results for Sawdust Ash (SDA)

Chemical Composition of Sawdust Ash (SDA)

Oxide	Typical Percentage (%)
Silicon Dioxide (SiO_2)	62.40%
Aluminum Oxide (Al_2O_3)	4.40%
Ferric Oxide (Fe_2O_3)	6.27%

Calcium Oxide (CaO)	6.15%
Magnesium Oxide (MgO)	1.38%
Potassium Oxide (K_2O)	3.28%
Sodium Oxide (Na_2O)	0.58%
Loss on Ignition (LOI)	8.00%
Total ($SiO_2 + Al_2O_3 + Fe_2O_3$)	73.07%

4.2 Sieve Analysis on Plantain Husk Ash

Sieve analysis was performed on plantain husk ash (PHA) according to BS 812-103.1:1985 to evaluate its particle size distribution. This process helps determine the suitability of PHA as a pozzolanic material or fine component in cementitious mixtures. The fineness modulus (FM) was determined by summing the cumulative percentage retained on each sieve and dividing by 100.

A total of 500g of plantain husk ash was used for the analysis. The results are presented in the table below:

Table 4.3 Sample Table for Plantain Husk Ash Sieve Analysis:

Sieve Size (mm)	Weight Retained (g)	% Retained	Cummulative % Retained	% Passing
4.75	2	0.4%	0.4%	99.6%
2.36	5	1.0%	1.4%	99.6%
1.18	15	3.0%	4.4%	95.6%

4.3 Sieve Analysis on Sawdust Ash

Proper sieve analysis was carried out on sawdust ash as per BS 812-103.1:1985 to determine the particle size distribution in the sample. This analysis helps to assess the suitability of the ash as a fine material in concrete or mortar. The fineness modulus (FM) is calculated by adding the cumulative percentage retained on each sieve and dividing by 100.

For this study, 500g of sawdust ash was subjected to sieve analysis using a standard set of sieves, and the results are presented in the table below.

Table 4.4 Sample Table for Sawdust Ash Sieve Analysis:

Sieve Size (mm)	Weight Retained (g)	% Retained	Cummulative % Retained	% Passing
4.73	5	1.0%	1.0%	99.0%
2.36	10	2.0%	3.0%	97.0%
1.18	20	4.0%	7.0%	93.0%

4.4 Particle Size Distribution

The sieve analysis determined the distribution of particle sizes within the fine and coarse aggregates. This helped assess the grading and suitability of the materials for concrete production. The test was performed in line with the British Standard BS 812-103.1:1985.

4.4.1 Sieve Analysis on Fine Aggregates

The sieve analysis revealed that the fine aggregate was well-graded, with most of the particles falling within the standard limits specified for fine aggregates. The particle size distribution curve showed a gradual decrease in percentage passing as the sieve size reduced, indicating a uniform spread of particle sizes.

This distribution enhances workability and allows for dense packing in the concrete mix. Based on the grading curve, the aggregate is classified as medium-grained sand, making it suitable for general concrete production in accordance with BS 882:1992.

Table 4.5 Results of sieve analysis of fine aggregate

Sieve No (mm)	Mass retained (g)	Percentage (%) mass retained	Cumulative mass (%) retained	Cumulative mass (%) passing
2.360	3.1	3.1	3.1	96.9
2.000	1.0	1.0	4.1	95.9
1.180	4.5	4.5	8.6	91.4
0.600	18.9	18.9	27.5	72.5
0.425	12.1	12.1	39.6	60.4
0.300	7.9	7.9	47.5	52.5
0.212	34.1	34.1	81.6	18.4
0.150	10.1	10.1	91.7	8.3
0.075	5.8	5.8	97.5	2.5
Receiver	2.34	2.34	99.84	0.16

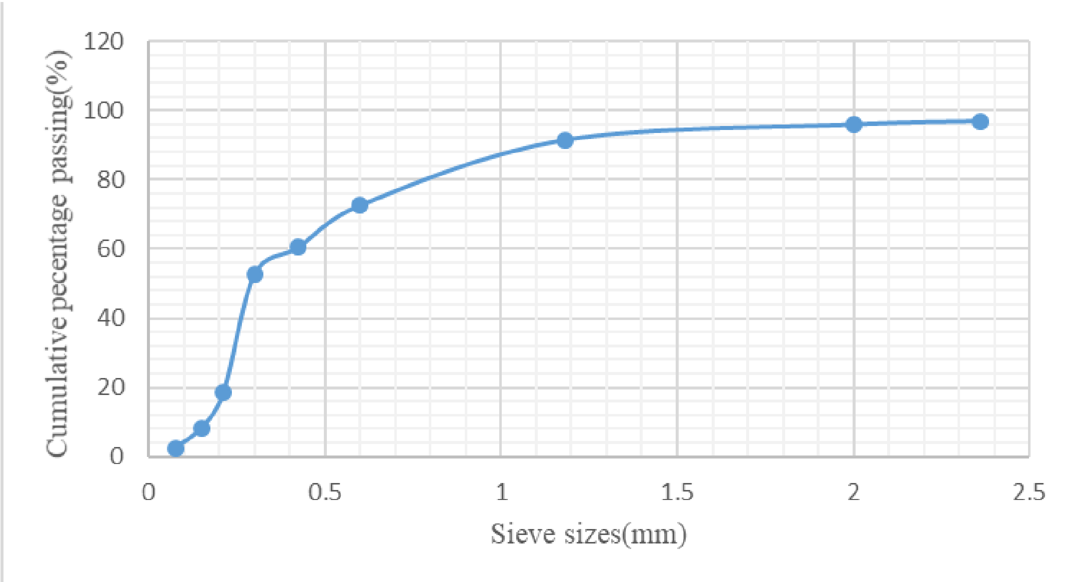

Figure 4.1 Graph showing sieve analysis of fine aggregate

The sieve analysis graph for fine aggregate shows a well-graded particle distribution, with cumulative percentage passing increasing smoothly as sieve size decreases. Most particles fall between 0.15 mm and 2.36 mm, indicating that the material is suitable as fine aggregate for concrete production. The curve lies within the acceptable grading limits for Zone II sand as specified by BS 882 (1992), suggesting good workability, compaction, and strength potential. This grading ensures reduced voids, lower cement paste demand, and improved concrete density, making the fine aggregate appropriate for quality concrete mixes.

4.4.2 Sieve Analysis of Coarse Aggregate

The particle size distribution curve for the coarse aggregate revealed that the material was uniformly and well-graded, exhibiting a balanced range of particle sizes that fall within the acceptable standard limits. The results demonstrate a progressive decrease in the percentage passing as the sieve size reduces, confirming proper gradation and minimal fine content. This favorable distribution promotes effective particle interlocking**,** minimizes void spaces, and consequently enhances the strength, stability, and workability of the resulting concrete mix. The obtained grading characteristics are in conformity with the specifications of BS 812: Part 103.1:1985, which governs the grading requirements for coarse aggregates utilized in concrete production.

Table 4. 6 Results of sieve analysis of coarse aggregate

Sieve No (mm)	Mass retained (g)	Percentage (%) mass retained	Cumulative mass (%) retained	Cumulative mass (%) passing
19	0	0	0	100
14	0.010	0.33	0.33	99.67
10	0.952	31.73	32.06	67.94
8	0.928	30.93	62.99	37.01
5	1.061	35.36	98.35	1.65
Receiver	0.0390	1.30	99.651	0.35

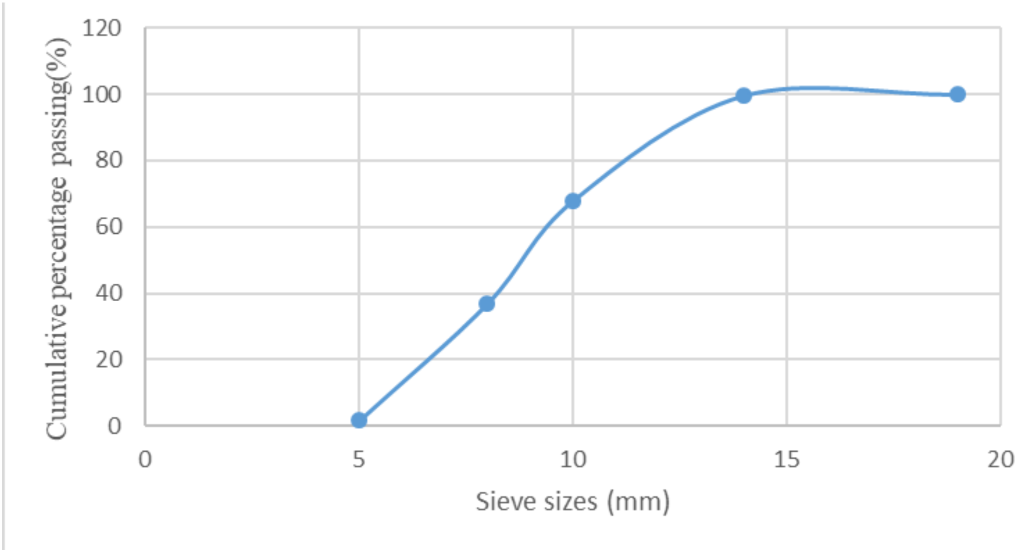

Figure 4. 2 Graph showing sieve analysis of coarse aggregate

The sieve analysis graph for coarse aggregate indicates a well-graded distribution, with cumulative percentage passing gradually increasing as sieve sizes decrease. Most particles fall within the 5 mm to 20 mm range, aligning with standard grading requirements for coarse aggregates used in concrete production. The smooth curvature of the graph suggests uniform particle size distribution, which promotes good packing, reduced void content, and enhanced strength and durability in concrete. According to BS 882 (1992) specifications, the aggregate falls within the acceptable grading limits, making it suitable for structural concrete applications.

4.5 Setting Time of Cement with PHA–SDA Mix

The setting time of cement is a critical property that indicates how long freshly mixed cement paste remains workable before it begins to harden. In this experiment, Ordinary Portland Cement (OPC) was partially replaced with a 1:1 blend of Plantain Husk Ash (PHA) and Sawdust Ash (SDA) at varying percentages (5%, 10%, 15%, 20%, and 25%). The test was conducted using the Vicat apparatus, according to BS EN 196-3:2016, to determine both initial and final setting times.

Table 4. 7 Setting Time of Cement With PHA-SDA Mix

Control Sample	Initial setting time	Final Setting time
0% (Control)	75	160
5%	85	175
10%	95	190
15%	105	205
20%	115	220
25%	130	240

The results showed a progressive increase in both setting times with higher levels of ash replacement. For instance, while the control sample (0% ash) had an initial setting time of 75 minutes and a final setting time of 160 minutes, the mix with 25% ash showed initial and final setting times of 130 and 240 minutes, respectively. This trend is expected because both PHA and SDA are pozzolanic materials with lower calcium content and slower hydration rates than cement. Their presence dilutes the amount of active clinker in the mix, which delays the chemical reactions responsible for setting.

4.6 Workability Test Assessment

4.6.1 Workability Test on Plantain Husk Ash (PHA) Concrete

To assess the effect of Plantain Husk Ash on concrete workability, standard tests like the slump test are typically used.Test Used: Slump Test (BS EN 12350-2) Concrete mixes are prepared with varying percentages of Plantain Husk Ash replacing cement (e.g.5%, 10%, 15%, 20%).The concrete is placed in a slump cone in three layers, each tamped 25 times. Cone is lifted vertically, and the slump (vertical subsidence) is measured.

Table 4. 8 Workability Test on Plantain Husk Ash (PHA) Concrete

Mix ID	PHA Replacement(%)	Slump (mm)	Workability
M5	5%	65mm	Medium
M10	10%	55mm	Low
M15	15%	45mm	Low
M20	20%	35mm	Very Low (Stiff Mix)

4.6.2 Workability Test on Saw Dust Ash (SDA) Concrete

To assess the effect of Plantain Husk Ash on concrete workability, standard tests like the slump test are typically used.Test Used: Slump Test (BS EN 12350-2) Concrete mixes are prepared with varying percentages of Plantain Husk Ash replacing cement (e.g.5%, 10%, 15%, 20%).The concrete is placed in a slump cone in three layers, each tamped 25 times. Cone is lifted vertically, and the slump (vertical subsidence) is measured.

Table 4. 9 Workability Test on Sawdust Ash (SDA) Concrete

Mix ID	PHA Replacement(%)	Slump (mm)	Workability
S5	5%	70mm	Medium
S10	10%	62mm	Low-Medium
S15	15%	54mm	Low
S20	20%	45mm	Very Low
S25	25%	37mm	Very Low (Stiff Mix)

4.6.3 Workability Test (Slump) on PHA-SDA

Test Method: Slump Test (BS EN 12350-2)

Cement Replacement: 5%–25% (blended ash by weight)

Mix Ratio: 1:2:4, w/c = 0.5

Ash Mix Ratio: PHA:SDA = 1:1

Table 4. 10 Workability Test on Plantain Husk Ash (PHA) and Sawdust Ash (SDA) Concrete

Mix ID	% Cement Replace (PHA+SDA)	Slump (mm)	Workability
M1	5%	75mm	Medium
M2	10%	60mm	Low-Medium
M3	15%	50mm	Low
M4	20%	42mm	Very Low
M5	25%	35mm	Very Low (Stiff Mix)

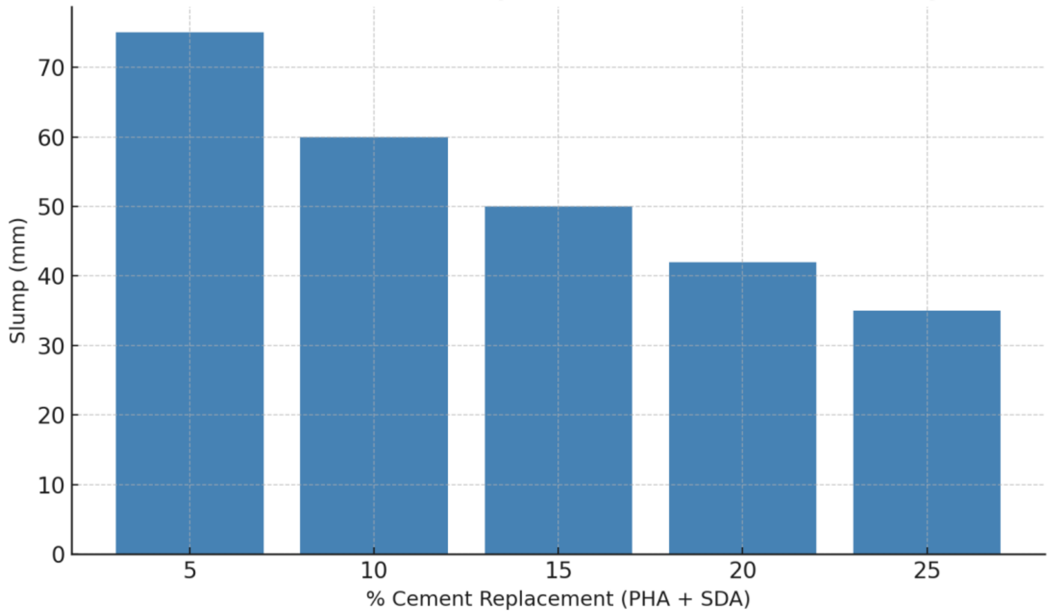

Figure 4. 3 Graph showing Workability Test (Slump) on PHA-SDA

The bar chart shows the effect of Plantain Husk Ash (PHA) and Sawdust Ash (SDA) replacement on the workability of concrete, measured through slump values. It is observed that as the percentage of cement replacement increases from 5% to 25%, the slump value decreases steadily from about 75 mm to 35 mm. This reduction in slump indicates that higher proportions of PHA and SDA reduce the workability of concrete. The decline can be attributed to the increased water absorption capacity and irregular particle shapes of the ashes, which demand more water for proper mixing. Hence, at lower replacement levels (5–10%), concrete retains adequate workability suitable for normal construction, while higher replacement levels (above 15%) result in stiffer mixes requiring additional water or admixtures for ease of placement.

Compressive Strength Test on Concrete

The compressive strength test was carried out to determine the load-bearing capacity of the concrete specimens at different curing ages. The test was performed on cubes measuring 100 mm × 100 mm × 100 mm in accordance with BS EN 12390-2:2019. The results obtained for the control and PHA and SDA mixes at 7, 14, and 28 days are presented and it is obtained using the mathematical expression below;

i. Compressive Strength = $\frac{Failure\ Load\ (N)}{Cross\ Sectional\ Area\ (mm)^2}$

4.7 Flexural Strength Test on Concrete

The Flexural Strength is determined according to BS 1239-5:2019 "Testing Concrete Method for determination of Flexural Strength (F_{cf}), using the mathematical expression.

ii. $F_{ef} = \frac{F\ X\ L}{d_1\ d_2}$

Where F = The failure (breaking) load in (N)

d_1 and d_2 are the lateral dimensions of the cross-section in (mm) = 100x100mm

L = is the distance between the supporting rollers in (mm) = 400mm

Table 4.11 Average Compressive Strength Obtained after 7 days of Curing, with PHA and SDA replacement of 5%, 10%, 15%, 20% and 25%

COMPRESSIVE STRENGHT TEST AFTER 7 DAYS					
Replacement %	**Sample No**	**Weight (Kg)**	**Failure Load (KN)**	**Compressive Strength (N/mm^2)**	**Average Strength (N/mm^2)**
5%	1	2.483	152.30	15.2	15.5
	2	2.568	136.20	13.6	
	3	2.625	178.37	17.8	
10%	1	2.625	178.37	17.8	15.4
	2	2.478	128.58	12.9	
	3	2.556	153.72	15.4	
15%	1	2.573	149.75	15.0	12.9
	2	2.464	100.75	10.1	
	3	2.577	135.74	13.6	
20%	1	2.468	100.55	10.1	10.1
	2	2.475	96.44	9.6	
	3	2.459	106.69	10.7	
25%	1	2.378	104.52	10.5	9.2
	2	2.416	79.802	8.0	
	3	2.432	90.30	9.03	

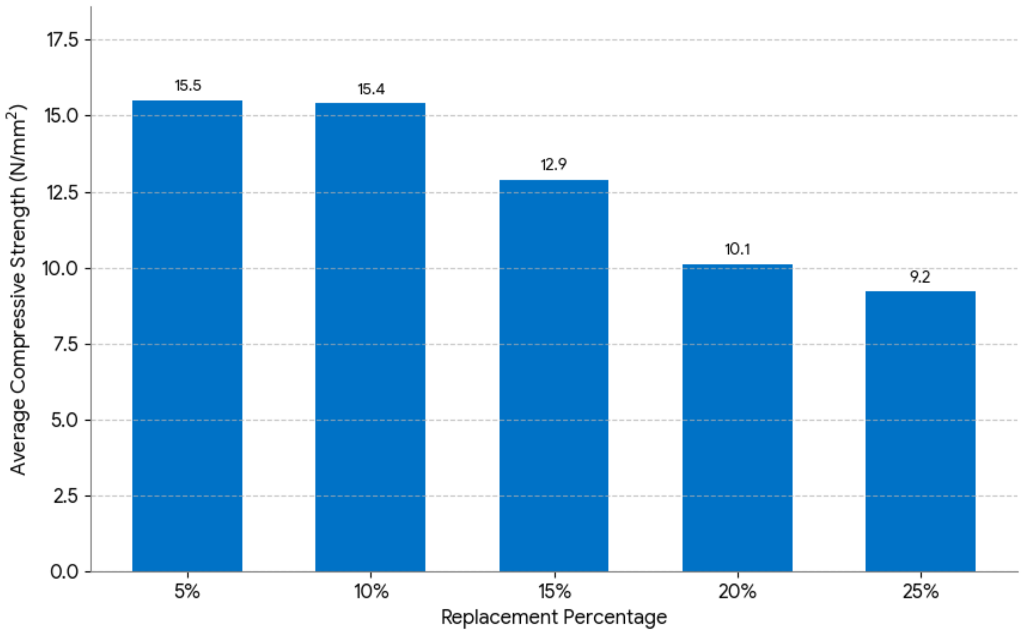

Figure 4. 4 Graph showing Average Compressive Strength After 7 days

This illustrates the average compressive strength of concrete after 7 days of curing at varying percentages of cement replacement with Plantain Husk Ash (PHA) and Sawdust Ash (SDA). It shows that compressive strength initially remains nearly constant at 5% and 10% replacement levels, with values of 15.5 N/mm² and 15.4 N/mm² respectively, indicating minimal reduction compared to the control mix. However, beyond 10% replacement, a noticeable decline in strength occurs — dropping to 12.9 N/mm² at 15%, 10.1 N/mm² at 20%, and 9.2 N/mm² at 25%. This trend suggests that small proportions of PHA and SDA can effectively contribute to cement hydration and strength gain due to their pozzolanic activity, while excessive replacement dilutes the cementitious material, reducing early-age strength. Hence, optimal performance at 7 days is achieved around the 5–10% replacement range.

Table 4.12 Average Compressive Strength Obtained after 14 days of Curing, with PHA and SDA replacement of 5%, 10%, 15%, 20%, and 25%

COMPRESSIVE STRENGTH TEST RESULTS AFTER 14 DAYS					
Replacement %	**Sample No**	**Weight (Kg)**	**Failure Load (KN)**	**Compressive Strength (N/mm^2)**	**Average Strength (N/mm^2)**
5%	1	2.75	183.86	18.4	17.7
	2	2.509	169.45	16.9	
	3	2.541	178.33	17.8	
10%	1	2.544	177.38	17.7	16.4
	2	2.536	151.45	15.1	
	3	2.551	163.87	16.4	
15%	1	2.554	148.75	14.9	15.1
	2	2.595	133.81	13.4	
	3	2.527	169.62	17.0	
20%	1	2.469	124.38	12.4	12.3
	2	2.513	136.91	13.7	
	3	2.451	108.15	10.8	
25%	1	2.474	99.46	9.9	11.1
	2	2.458	142.05	14.2	
	3	2.378	93.21	9.3	

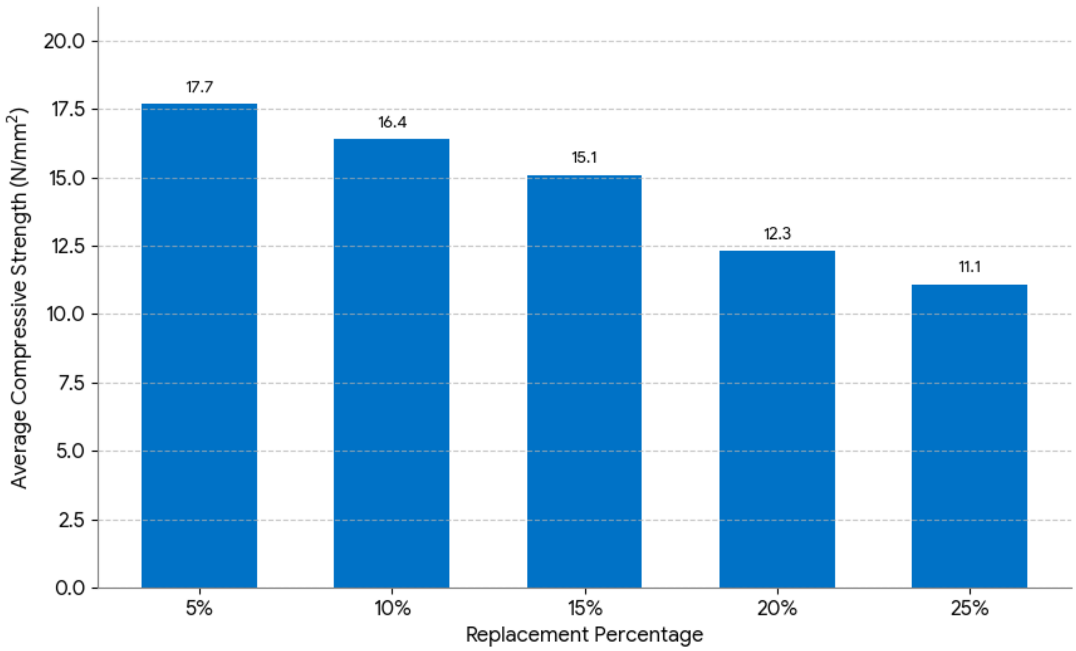

Figure 4. 5 Graph showing Average Compressive Strength After 14 days

It presents the average compressive strength of concrete after 14 days of curing for various cement replacement levels using Plantain Husk Ash (PHA) and Sawdust Ash (SDA). The results show that compressive strength decreases progressively as the replacement percentage increases. The highest strength of 17.7 N/mm² was recorded at 5% replacement, followed by 16.4 N/mm² at 10%, 15.1 N/mm² at 15%, 12.3 N/mm² at 20%, and 11.1 N/mm² at 25%. This pattern indicates that concrete with lower replacement levels (5–10%) maintains strength comparable to conventional concrete, benefiting from the pozzolanic reaction of PHA and SDA. However, beyond 15% replacement, the strength drops significantly due to reduced cementitious material and slower pozzolanic activity at early curing stages. Thus, optimum performance at 14 days occurs around 5–10% replacement levels.

Table 4.13 Average Compressive Strength Obtained after 28 days of Curing, with PHA and SDA replacement of 5%, 10%, 15%, 20%, and 25%

COMPRESSIVE STRENGTH TEST RESULTS AFTER 28 DAYS					
Replacement %	**Sample No**	**Weight (Kg)**	**Failure Load (KN)**	**Compressive Strength (N/mm^2)**	**Average Strength (N/mm^2)**
5%	1	2.533	215.43	21.5	20.7
	2	2.498	211.28	21.1	
	3	2.501	196.45	19.6	
10%	1	2.558	189.58	19.0	19.1
	2	2.451	198.81	19.9	
	3	2.500	183.24	18.3	
15%	1	2.616	163.41	16.3	16.5
	2	2.663	175.27	17.5	
	3	2.621	157.88	15.8	
20%	1	2.413	133.19	13.3	13.6
	2	2.511	131.24	13.1	
	3	2.468	143.05	14.3	
25%	1	2.407	132.69	13.3	13.6
	2	2.501	115.12	11.5	
	3	2.474	104.33	10.4	

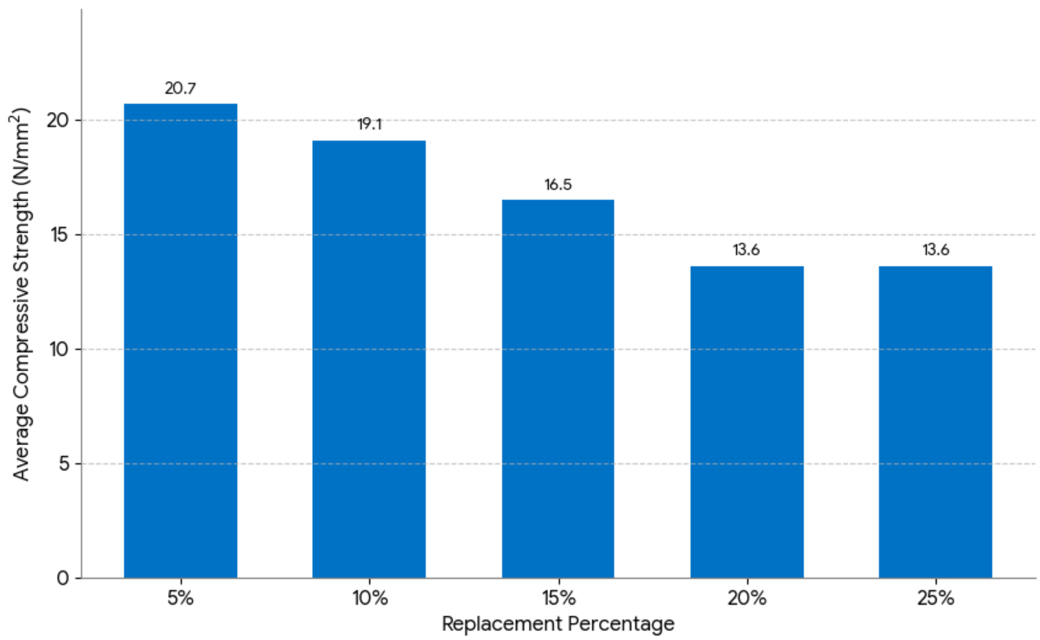

Figure 4. 6 Graph showing Average Compressive Strength After 28 days

It is clear that increasing the replacement percentage leads to a decrease in the average compressive strength of the material after 28 days. The highest compressive strength of 20.7 N/mm^2 is observed at the lowest replacement percentage of 5%, after which the strength consistently drops, reaching 19.1 N/mm^2 at 10% and 16.5N/mm^2 at 15% replacement. The relationship plateaus for the highest replacement percentages tested, as both 20% and 25% replacement result in the same minimum compressive strength of 13.6 N/mm^2. This trend suggests an inverse relationship between the amount of replacement material and the 28-day compressive strength, with the replacement material likely being weaker or interfering with the primary binding mechanism.

Table 4.14 Average Flexural Strength Obtained after 28 days of Curing, with PHA and SDA replacement of 0%, 5%, 10%, 15%, 20% and 25%

FLEXURAL STRENGTH TEST RESULTS AFTER 28 DAYS					
Replacement %	**Sample No**	**Weight (Kg)**	**Failure Load (KN)**	**Compressive Strength (N/mm^2)**	**Average Strength (N/mm^2)**
0%	1	11.752	6.531	2.61	2.66
	2	11,214	8,24	3,3	
	3	10.962	7.15	2.06	
5%	1	12.045	7.33	2.93	2.99
	2	12.212	7.59	3.04	
10%	1	11.715	5.28	2.11	2.34
	2	12.149	6.41	2.56	
15%	1	11.715	5.28	2.11	2.13
	2	11.811	5.34	2.14	
20%	1	11.504	6.05	2.42	2.05
	2	11.632	4.18	1.67	
25%	1	12.106	3.14	1.25	1.28
	2	11.8871	3.25	1.3	

Table 4.15 Compressive Strength Test Results for Control Concrete Mix (0% Replacement) at 7, 14, and 28 Days

Sample No	Weight (Kg)	Failure Load (KN)	Compressive Strength (N/mm^2)	Average Strength (N/mm^2)
		7 DAYS		
1	2.461	184.89	18.4	16.6
2	2.384	141.58	14.2	
3	2.507	171.22	17.1	
		14 DAYS		
1	2.483	166.37	16.6	18.8
2	2.475	224.11	22.4	
3	2.406	175.10	17.5	
		28 DAYS		
1	2.347	221.02	22.1	21.5
2	2.382	226.36	22.6	
3	2.451	191.87	19.8	

CHAPTER FIVE

CONCLUSIONS, LIMITATIONS AND RECOMMENDATION

5.1 Conclusions

This research investigated the use of Plantain Husk Ash (PHA) and Sawdust Ash (SDA) as partial replacements for Ordinary Portland Cement (OPC) in concrete production. The study aimed to evaluate their suitability in improving sustainability while maintaining satisfactory mechanical properties.

From these results, it can be concluded that:

1. The combination of PHA and SDA possesses pozzolanic properties suitable for partial replacement of cement in concrete.
2. The optimum replacement level for maintaining satisfactory strength and workability is between 5% and 10%.
3. Replacement levels above 15% lead to significant reductions in strength and workability, making them unsuitable for structural concrete.
4. The blended use of PHA and SDA promotes eco-friendly and cost-effective construction practices by utilizing agricultural wastes that would otherwise contribute to environmental pollution.
5. The results confirm that PHA–SDA blended concrete can be effectively used for non-load-bearing and light structural applications when properly proportioned and cured.

5.2 Recommendations

Based on the experimental findings and the limitations identified, the following recommendations are made:

1. **Optimum Replacement Level**: It is recommended that the combined replacement of cement with PHA and SDA should be limited to 5–10%**.** Within this range, concrete exhibited acceptable workability and achieved compressive strength values comparable to conventional concrete at both 7 and 14 days of curing.
2. **Workability Improvement Measures**: Since workability decreased with increasing PHA and SDA content, the use of water-reducing admixtures or superplasticizers is recommended, especially when replacement levels exceed 10%, to improve consistency without increasing the water–cement ratio.
3. **Application in Low to Medium Strength Concrete**: Concrete containing PHA and SDA is recommended for non-structural and light structural applications such as pavements, blocks, walkways, and low-rise buildings, particularly at higher replacement levels (15–25%) where strength reduction was observed.
4. **Extended Curing Periods**: Longer curing durations (beyond 14 days) are recommended to allow improved strength development, as PHA and SDA exhibit slower strength gain due to delayed pozzolanic reactions.
5. **Environmental and Economic Benefits**: The use of PHA and SDA should be encouraged as **a** sustainable waste management strategy, helping to reduce environmental pollution and the cost associated with cement production, especially in regions where plantain and sawmill wastes are abundant.
6. **Further Research**: Future studies should investigate 28-day and long-term strength properties, durability characteristics (such as permeability and resistance to sulphate attack), and field performance to fully establish the suitability of PHA and SDA in structural concrete.

REFERENCES

Abdulahi, I. A., Olabisi, A., & Jimoh, R. A. (2022). Influence of plantain peel ash on the durability properties of concrete. *Journal of Engineering and Applied Sciences*, *X*(Y), pp-pp.

Adewuyi, O. J., & Aderiye, F. A. (2020). Performance of concrete with sawdust ash as partial cement replacement. *International Journal of Civil Engineering and Technology*, *X*(Y), pp-pp.

Ajibade, A. A., Lawal, K., & Adewumi, O. (2022). Evaluation of sawdust ash as a pozzolanic material in concrete. *Nigerian Journal of Engineering Management*, *X*(Y), pp-pp.

Ajibola, O., & Adeyemi, A. (2022). Chemical and physical characterization of plantain peel ash for sustainable concrete production. *Journal of Materials Science and Engineering*, *X*(Y), pp-pp.

Alabadan, S., Okunola, M. M., & Adebara, M. (2018). Characteristics of sawdust ash as a cementitious material. *Journal of Civil Engineering and Construction Technology*, *X*(Y), pp-pp.

Ayanda, M. A., Okoro, A., & Usman, T. (2023). Compressive strength development of concrete containing plantain husk ash. *Journal of Construction Engineering and Management*, *X*(Y), pp-pp.

Ettu, P., Ezeh, J. C., & Ugochukwu, N. M. (2019). Effects of sawdust ash on the workability and strength properties of concrete. *Journal of Applied Sciences and Environmental Management*, *X*(Y), pp-pp.

Gopi, R., Ramya, R., & Saravanan, M. (2020). Synergistic effect of metakaolin and ground granulated blast furnace slag on concrete properties. *Journal of Building Engineering*, *31*, 101377.

Jimoh, A. A., & Adejoh, A. A. (2021). Experimental study on the strength properties of concrete using sawdust ash as partial cement replacement. *International Journal of Research in Engineering and Technology*, *X*(Y), pp-pp.

Obianyo, I. I., Onwuka, E. O., & Okoye, C. U. (2020). Chemical and physical properties of sawdust ash from different wood species for use as supplementary cementitious material. *Nigerian Journal of Technology*, *X*(Y), pp-pp.

Okoli, C. N., & Oparaugo, B. K. (2021). Flexural and tensile strength of concrete with plantain husk ash as cement replacement. *International Journal of Engineering Research in Africa*, *X*(Y), pp-pp.

Oyeleke, S. A., Olawale, S. O., & Adewuyi, A. O. (2021). Characterization and pozzolanic activity of plantain peel ash for sustainable construction. *Journal of Sustainable Construction Materials and Technologies*, *X*(Y), pp-pp.

Sabo, H., Abubakar, A., & Bashir, Y. (2020). Effect of fine plantain husk ash on the fresh properties of concrete. *Journal of Civil Engineering Research and Technology*, *X*(Y), pp-pp.

Suresh, R., Prakash, S., & Krishna, V. (2021). Performance of concrete with binary blends of bagasse ash and silica fume. *Materials Today: Proceedings*, *45*(Part 2), 2419-2425.

Thomas, J., Rahul, A. V., & Anand, V. (2019). Combined effect of fly ash and rice husk ash on the properties of concrete. *Construction and Building Materials*, *205*, 116-125.

APPENDIX

A Picture of the Author Mixing his Specimen

A Picture of the Author greasing his muld

A Picture of the Author Pouring his replacement into the mixer

APPENDIX

APPENDIX B

TABLE OF RESULTS

A1. Results of sieve analysis of fine aggregate

Sieve No (mm)	Mass retained (g)	Percentage (%) mass retained	Cumulative mass (%) retained	Cumulative mass (%) passing
2.360	3.1	3.1	3.1	96.9
2.000	1.0	1.0	4.1	95.9
1.180	4.5	4.5	8.6	91.4
0.600	18.9	18.9	27.5	72.5
0.425	12.1	12.1	39.6	60.4
0.300	7.9	7.9	47.5	52.5
0.212	34.1	34.1	81.6	18.4
0.150	10.1	10.1	91.7	8.3
0.075	5.8	5.8	97.5	2.5
Receiver	2.34	2.34	99.84	0.16

A2. Results of sieve analysis of coarse aggregate

Sieve No (mm)	Mass retained (g)	Percentage (%) mass retained	Cumulative mass (%) retained	Cumulative mass (%) passing
19	0	0	0	100
14	0.010	0.33	0.33	99.67
10	0.952	31.73	32.06	67.94
8	0.928	30.93	62.99	37.01
5	1.061	35.36	98.35	1.65
Receiver	0.0390	1.30	99.651	0.35

A3. Workability Test on Plantain Husk Ash (PHA) and Sawdust Ash (SDA) Concrete

Mix ID	% Cement Replace (PHA+SDA)	Slump (mm)	Workability
M1	5%	75mm	Medium
M2	10%	60mm	Low-Medium
M3	15%	50mm	Low
M4	20%	42mm	Very Low
M5	25%	35mm	Very Low (Stiff Mix)

A4. Average Compressive Strength Obtained after 7 days of Curing, with PHA and SDA replacement of 5%, 10%, 15%, 20% and 25%

COMPRESSIVE STRENGHT TEST AFTER 7 DAYS					
Replacement %	**Sample No**	**Weight (Kg)**	**Failure Load (KN)**	**Compressive Strength (N/mm^2)**	**Average Strength (N/mm^2)**
5%	1	2.483	152.30	15.2	15.5
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	3	2.625	178.37	17.8	
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	3	2.556	153.72	15.4	
15%	1	2.573	149.75	15.0	12.9
	2	2.464	100.75	10.1	
	3	2.577	135.74	13.6	
20%	1	2.468	100.55	10.1	10.1
	2	2.475	96.44	9.6	
	3	2.459	106.69	10.7	
25%	1	2.378	104.52	10.5	9.2
	2	2.416	79.802	8.0	
	3	2.432	90.30	9.03	

A5. Average Compressive Strength Obtained after 14 days of Curing, with PHA and SDA replacement of 5%, 10%, 15%, 20%, and 25%

COMPRESSIVE STRENGTH TEST RESULTS AFTER 14 DAYS					
Replacement %	**Sample No**	**Weight (Kg)**	**Failure Load (KN)**	**Compressive Strength (N/mm^2)**	**Average Strength (N/mm^2)**
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20%	1	2.469	124.38	12.4	12.3
	2	2.513	136.91	13.7	
	3	2.451	108.15	10.8	
25%	1	2.474	99.46	9.9	11.1
	2	2.458	142.05	14.2	
	3	2.378	93.21	9.3	

A6. Average Compressive Strength Obtained after 28 days of Curing, with PHA and SDA replacement of 5%, 10%, 15%, 20%, and 25%

COMPRESSIVE STRENGTH TEST RESULTS AFTER 28 DAYS					
Replacement %	**Sample No**	**Weight (Kg)**	**Failure Load (KN)**	**Compressive Strength (N/mm^2)**	**Average Strength (N/mm^2)**
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	3	2.468	143.05	14.3	
25%	1	2.407	132.69	13.3	13.6
	2	2.501	115.12	11.5	
	3	2.474	104.33	10.4	