

**PERFORMANCE EVALUATION OF CEMENT PARTIALLY REPLACED WITH A
BLEND OF PLANTAIN AND BANANA PEEL ASH IN CONCRETE.**

BY

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**A PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING
(B.Eng) DEGREE**

IN

**THE DEPARTMENT OF CIVIL ENGINEERING (STRUCTURAL ENGINEERING
PROGRAMME),**

FACULTY OF ENGINEERING,

UNIVERSITY OF BENIN, BENIN CITY, NIGERIA

FEBRUARY, 2025.

CERTIFICATION

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DEDICATION

This work is dedicated to my parents Mr. and Mrs. M.O Inegbedion for their unfailing love, prayers and support throughout this journey.

ACKNOWLEDGMENT

First and foremost, I would like to express my profound gratitude to Almighty God, who has been my rock, strength, and inspiration throughout this journey. Your divine guidance, wisdom, and provision have been my constant companion, and I am thankful for Your faithfulness.

To myself, I acknowledge the hard work, dedication, and perseverance that I invested in this project. Completing this project has been a transformative experience, and I am proud of my resilience and determination.

My Sincere gratitude goes to my project supervisor Dr. (Mrs) L.O Bobor for her expert guidance and constructive feedback throughout this research work.

I also want to thank my HOD, Engr Dr. (Mrs) N.I. Ihimekpen, Engr. E. Oria-Usifo, Engr. Dr. R. Ilaboya and the entire staffs for their assistance in one great way or another during the course of my project. This work would definitely not have been this successful without any of you.

To my family, my mother and father and to my siblings, I express my heartfelt gratitude for their unwavering support, love, and encouragement. Your sacrifices, patience, and understanding have meant the world to me, and I am thankful for the countless ways you have contributed to my success.

ABSTRACT

This study aims to investigate the feasibility of using a blend of plantain and banana peel ash (PBPA) as a partial replacement for cement in concrete. The study seeks to evaluate the effects of PBPA on the workability, compressive strength, and flexural strength of concrete, with a view to reducing the environmental impact of concrete production.

The workability of the concrete mixtures was evaluated using the slump test, in accordance with ASTM C143/C143M-15a. The compressive strength was determined using the standard compressive strength test, as outlined in BS EN 12390-3:2019. The flexural strength was assessed using the modulus of rupture test, in line with ASTM C78/C78M-18. These tests enabled a comprehensive evaluation of the effects of PBPA on the mechanical properties of concrete.

The results showed that 0% replacement of cement with PBPA and coarse aggregate produced a slump value of 40mm while 5 to 15% replacement produced slump values of 39.7mm, 42.7mm, 51.3mm respectively. From the rate of decrease, this indicated that increasing the PBPA content decreases the workability of the mix, while the compressive and flexural strengths were reduced by up to 20% at 28 days. However, the concrete mixtures with up to 10% PBPA replacement still met the strength requirements for grade M20 concrete. The findings suggest that PBPA can be used as a supplementary cementitious material to reduce the environmental impact of concrete production.

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CHAPTER ONE

INTRODUCTION

1.1 Background of study

The construction industry is a significant contributor to environmental degradation, primarily due to the high demand for natural resources and energy-intensive processes. The production of concrete, a fundamental construction material, is a significant contributor to greenhouse gas emissions and resource depletion (Noguchi et al, 2015). This study aims to investigate the potential of sustainable concrete production by partially substituting cement with a blend of plantain and banana peel ash. The structural integrity and strength of the resulting concrete will be evaluated to determine its viability as a sustainable alternative to traditional concrete. The use of locally available and waste materials, such as plantain peels, offers a promising solution to reducing the environmental footprint of concrete production while maintaining its structural performance.

Concrete is a widely used construction material, accounting for approximately 70% of the world's construction materials. However, the production of concrete has significant environmental implications, including:

- a) Depletion of natural resources: Extraction of natural aggregates and cement production contribute to resource depletion.
- b) Greenhouse gas emissions: Cement production is a significant source of CO₂ emissions, contributing to climate change.
- c) Waste generation: Concrete production results in waste materials, including dust and excess concrete.

In recent years, researchers have explored sustainable alternatives to traditional concrete materials. Plantain and banana peel ash, rich in silica and alumina, have been recognized as potential cement replacement materials (Ogunbayo et al, 2020 and Akinyele et al, 2019)..

Despite the potential benefits of using this sustainable materials, there is a need for comprehensive research on its performance in concrete production. The strength of materials and structural integrity are critical factors in concrete production, and the use of alternative materials must not compromise these properties.

This study aims to investigate the performance of concrete with cement partially replaced with a blend of plantain and banana peel ash. The strength of the material and its structural integrity will be evaluated to determine the viability of this sustainable concrete mixture.

1.2 Statement of the Problem

The growing demand for sustainable construction materials has driven the search for alternative materials in concrete production. This has led to the investigation of plantain and banana peel ash as a potential partial replacement for cement. However, a comprehensive evaluation of the suitability of these alternative materials in concrete mixture is essential, with a particular focus on their impact on the properties and performance of concrete (<http://en.Wikipedia.org>).

Some challenges experienced which led to the idea of the partial substitution of cement in concrete for construction include;

- i.) **High cost:** Concrete is a costly material, especially when considering the cost of cement and its transportation.(Neville, 2019 and Adeniyani,2019)

- ii.) **Environmental impact:** Cement manufacturing is a significant source of greenhouse gas emissions, contributing to climate change. (Oloruntade, 2020)
- iii.) **Sustainability:** The production process and raw materials used in concrete construction can be unsustainable and non-renewable.(Kumaar, 2020)
- iv.) **Maintenance:** Concrete structures require regular maintenance to prevent deterioration and extend their lifespan.
- v.) **Waste generation:** Concrete construction can generate significant waste, including excess material and packaging.

By exploring alternative materials and technologies, like the use plantain and banana peel ash, we can work towards addressing these challenges and creating more sustainable and cost-effective construction practices.

1.3 Aim and Objectives

The aim of this study is to evaluate the performance of concrete with cement partially replaced with a blend of plantain and banana peel ash with a view to contributing to the development of sustainable and environmentally friendly construction materials. The Objectives are:

- i.) To study the effect of partially replacing cement with different percentages of plantain-banana peel ash on the workability of concrete.
- ii.) To evaluate the compressive strength of concrete produced with cement partially replaced with a blend of plantain and banana peel ash at various percentages.
- iii.)To determine the flexural strength of concrete produced with cement partially replaced with a blend of plantain and banana peel ash at various percentages.

iv.) To compare the performance of concrete with partial replacement of cement with standard conventional concrete.

1.4 Scope Of Study

This research will conduct a comprehensive investigation into the effects of partially replacing cement with dried plantain and banana peel ash in concrete mixture, examining the resulting physical, mechanical, and durability properties of the modified concrete. Concrete cubes will be casted with a mix design of 1:2:4 (cement: sand: coarse aggregate) and a water-cement ratio of 0.5. This will be adopted for a total of 5 concrete mixtures, including 1 control mix (0%) and 4 sustainable concrete mixes (5%, 10%, 15% and 20%) with varying proportions of plantain and banana peel ash. 6 cubes will be casted for each mix making a total of Thirty (30) concrete cubes.

Tests will be conducted on fresh and hardened concrete properties, including slump test, compressive strength test, flexural strength test, Aggregate crushing value (ACV) tests, Aggregate Impact value(AIV) and density test.

1.5 Justification of Study

The construction industry is a significant contributor to environmental degradation, accounting for approximately 40% of global energy consumption, 30% of greenhouse gas emissions, and 50% of natural resource depletion. The production of cement, a primary component of concrete, is a major factor in these statistics, as it requires large amounts of energy and water and generates substantial CO₂ emissions.

The construction industry's reliance on non-renewable resources and its significant environmental footprint necessitate the exploration of sustainable alternatives. The partial

replacement of cement with a blend of plantain and banana peel ash offers advantages, including: Reduced energy consumption, Lower CO₂ emissions And Improved waste management.

By investigating the performance of concrete with partially substituted cement, this study aims to contribute to the development of sustainable and environmentally friendly construction materials, aligning with the United Nations' Sustainable Development Goals (SDGs) and promoting a more resilient and sustainable built environment.

However, it is crucial to approach this study with caution, as the use of unconventional materials in concrete can have unpredictable effects on its properties. Previous studies have shown that the use of plantain and banana peel ash can improve the workability and durability of concrete (Olanipekun et al., 2020; Awoyera et al., 2020), but the structural integrity and strength of the material must be carefully evaluated. Other researchers have investigated the use of alternative materials in concrete, such as:

- (i) Palm kernel shell as a partial replacement for coarse aggregate (Ogunwemimo, et al 2019, Salami, et al 2020, & Familusi et al, 2019)
- (ii) Sawdust and palm kernel shell as a replacement for fine and coarse aggregate (Ogunwemimo, et al 2019, Salami, et al 2020, & Familusi et al, 2019)
- (iii) Plantain peels ash as an admixture in concrete (Ahmad et al, 2016, & Maaruf et al, 2016)

These studies suggest that the use of waste materials in concrete can improve its properties and reduce environmental impacts.

CHAPTER TWO

LITERATURE REVIEW

2.0 Preamble

Studies have shown that using sustainable materials in concrete production can improve its environmental footprint. Researchers have explored the potential of using a blend of plantain and banana peel ash as a partial replacement for cement.

Omatola et al. (2019) reported that plantain peels ash reduced the compressive strength of concrete but improved its workability. Similarly, Singh et al. (2020) investigated the effect of partially replacing cement with a blend of plantain and banana peel ash and found improved compressive strength and reduced water absorption. Adak et al. (2020) also reported improved compressive strength and durability with the use of bamboo and plantain peels ash in concrete.

These studies suggest that a blend of plantain and banana peel ash in concrete can improve its performance and sustainability. However, more research is needed to fully understand the potential of these materials and their optimal usage in concrete production.

2.1 Traditional Concrete Composition and Properties

2.1.1 Concrete

Concrete is a fundamental material in construction, but its production has significant environmental impacts (Hansen et al., 2018). This literature review explores the use of sustainable materials, specifically a blend of plantain and banana peel ash (Gupta et al., 2020), as partial replacement for cement in concrete. The study investigates the physical, mechanical, and durability properties of sustainable concrete mixes and compares them to traditional

concrete. The results show promising potential for sustainable concrete production, reducing the environmental footprint of the construction industry.

2.1.2 Compositions of Traditional Concrete

- (i) Cement (10-15%): Ahmed et al. (2018) noted that cement provides strength and binding properties. The binding agent that holds the aggregate particles together, typically Portland cement (Hansen et al., 2018).
- (ii) Water (15-20%): Omatola et al. (2019) emphasized the importance of water in hydrating cement and creating workability. Water also hydrates the cement, allowing it to bind with the aggregate (Kumar et al., 2020).
- (iii) Aggregates (60-70%): Inert particles like sand, gravel, or crushed stone that provide strength and volume (Singh et al., 2019).
- (iv) Air (5-10%): Adak et al. (2020) discussed the impact of entrapped air voids on workability and durability.

2.1.3 Properties of Traditional Concrete

- (i) Compressive strength (2,000-6,000 psi): Raj et al. (2020) reported compressive strength values for traditional concrete. It decreases with the increase in percentage of banana peel ash and dried plantain peel ash. The blend of banana peel ash and dried plantain peel ash may have a synergistic effect that further decreases compressive strength.
- (ii) Tensile strength (300-700 psi): Kumar et al. (2020) discussed the tensile strength of concrete.

- (iii) Durability: Sharma et al. (2019) emphasized the importance of durability in concrete structures. : The decreased compressive strength may result in lower durability.
- (iv) Workability: Patel et al. (2018) highlighted the significance of workability in concrete placement and finishing and stated that the workability of the concrete may decrease as the percentage of banana peel ash and dried plantain peel ash increases.
- (v) Density (2,300-2,400 kg/m³): Gupta et al. (2019) reported density values for traditional concrete and may be affected by the addition of a blend of banana peel ash and dried plantain peel ash.
- (vi) Porosity (10-20%): Verma et al. (2020) discussed the impact of porosity on concrete properties.
- (vii) Permeability: Sharma et al. (2019) reported permeability values for traditional concrete.
- (viii) Shrinkage (0.5-1.5%): Singh et al. (2020) discussed the impact of shrinkage on concrete structures.

2.1.4 Concrete Mix Design and Performance

Concrete mix design is a critical process in concrete construction, as it determines the properties and performance of the concrete. The standard mix design of concrete typically consists of cement, water, aggregates (sand, gravel, or crushed stone), and admixtures (chemical additives). The cement content in concrete mix design varies depending on the type of cement and the desired strength of the concrete. Generally, the cement content ranges from 300 to 500 kg/m³ (Ahmed et al., 2018). However, some researchers have used higher cement contents, up to 600 kg/m³, to achieve higher strengths (Singh et al., 2020).

The water content in concrete mix design is critical, as it affects the workability and strength of the concrete. The water-to-cement ratio (w/c) is typically ranging from 0.4 to 0.6 (Omatola et al., 2019). However, some researchers have used lower w/c ratios, down to 0.3, to achieve higher strengths (Adak et al., 2020). The aggregate content in concrete mix design provides strength and volume to the concrete. The aggregate-to-cement ratio (a/c) typically ranges from 3 to 6 (Raj et al., 2020). However, some researchers have used higher a/c ratios, up to 8, to achieve higher strengths (Kumar et al., 2020).

Admixtures are chemical additives used to improve the properties of concrete. The most common admixtures are air-entraining agents, retarding agents, and accelerating agents (Sharma et al., 2019).

Research has shown the chemical composition of fine and coarse aggregates has a significant impact on concrete performance and strength, this study highlights the importance of optimizing aggregate gradation for desired concrete properties and contributed valuable insights into optimizing concrete mix designs and enhancing the durability of concrete structures. Emmanuel et al. (2023) examined the durability of concrete made with fine aggregate from various sources using mathematical modeling.

Memon et al. (2023), Aves (2022), Emmanuel et al. (2023), and Jackson and Akomah (2018) contributed valuable insights into the intricate relationship between fine aggregates and concrete properties. Notably, the study by Ozyildirim et al. (2020) delves into the effect of fine aggregate characteristics on concrete strength and durability.

2.1.5 Common Issues of Traditional Concrete

Traditional concrete has several limitations and issues that have been widely reported in the literature.

(a) Durability Issues

- (i) Carbonation: a major cause of concrete deterioration (Hansen et al., 2018)
- (ii) Chloride attack: leads to corrosion of steel reinforcement (Ann et al., 2019)
- (iii) Sulfate attack: causes expansion and cracking (Raj et al., 2020)

(b) Environmental Impact

- (i) High carbon footprint: cement production contributes to greenhouse gas emissions (Singh et al., 2020)
- (ii) Resource depletion: extraction of raw materials affects the environment (Kumar et al., 2020)

(c) Structural Issues

- (i) Cracking: leads to water penetration and reinforcement corrosion (Sharma et al., 2019)
- (ii) Shrinkage: causes structural damage and cracking (Verma et al., 2020)

(d) High Maintenance Costs

- (i) Repair and replacement: costly and time-consuming (Patel et al., 2018)
- (ii) Maintenance frequency: high due to durability issues (Gupta et al., 2019)

2.2 Need for Sustainable Alternatives in Concrete Production

The need for sustainable alternatives in concrete is pressing due to the environmental, social, and economic concerns associated with traditional concrete;

(a) Environmental Impact:

- (i) Cement production contributes to 8% of global CO₂ emissions (Hansen et al., 2018)
- (ii) Resource extraction leads to habitat destruction and water pollution (Singh et al., 2019).

(b) Social Concerns:

- (i) Health risks from cement dust and aggregate extraction (Kumar et al., 2020)
- (ii) Displacement of communities due to quarrying and mining (Rahman et al., 2019).

(c) Economic Factors:

- (i) Increasing costs of raw materials and energy (Gupta et al., 2020).
- (ii) Infrastructure deterioration and maintenance needs (Sharma et al., 2020).

2.2.1 Environmental Impact of Cement and Aggregate Production

The environmental impact of cement and aggregate production includes:

(a) Cement production:

- (i) Greenhouse gas emissions: 8% of global CO₂ emissions (Hansen et al., 2018)
- (ii) Energy consumption: High energy requirements (Gupta et al., 2020)
- (iii) Water pollution: Cement production affects water quality (Singh et al., 2019)
- (iv) Land degradation: Limestone quarrying leads to habitat destruction (Kumar et al., 2020)

(b) Aggregate production:

- (i) Resource depletion: Extraction of natural resources (Rahman et al., 2019)
- (ii) Habitat destruction: Quarrying leads to loss of biodiversity (Sharma et al., 2020)
- (iii) Water pollution: Aggregate extraction affects water quality (Gupta et al., 2020)
- (iv) Land degradation: Quarrying leads to soil erosion and landslides (Kumar et al., 2020)

2.2.2 Global Efforts to Reduce Emission of CO₂ and other gases in construction

The construction sector is a significant contributor to greenhouse gas emissions, primarily due to energy consumption and building material production.

Global efforts to reduce CO₂ and other gases in construction involve sustainable building materials, energy efficiency measures, green building certifications, circular economy approaches, and research and development in new technologies and materials.

(a) **Sustainable building materials:** The UN Environment Programme and the Yale Center for Ecosystems + Architecture recommend avoiding unnecessary extraction and production, shifting to regenerative materials, and improving de-carbonization of conventional materials (Zhang et al., 2020). It plays a crucial role in reducing CO₂ and other greenhouse gases

- (i) **Low-carbon cement:** It reduces CO₂ emissions by 50-70% (Zhang et al., 2020) and can be produced with waste materials like fly ash and slag (Wang et al., 2019)
- (ii) **Recycled materials:** This way it conserves natural resources and reduces waste (Wang et al., 2019) and it can also reduce CO₂ emissions by up to 50% (Buchanan et al., 2018).
- (iii) **Sustainably sourced wood products:** It promotes responsible forestry practices and reduces deforestation (Buchanan et al., 2018) and it can store carbon for decades, reducing atmospheric CO₂ (Kutnar et al., 2018)
- (iv) **Bamboo:** Bamboo has a lower carbon footprint than traditional building materials (Zatul et al., 2017) and it can sequester more CO₂ than many other plants (Lobovikov et al., 2012)

- (v) **Straw bale construction:** This reduces CO₂ emissions by up to 75% compared to traditional building methods (Morton et al., 2017) and thus provides insulation and reduces energy consumption (Morton et al., 2017)

These sustainable building materials not only reduce CO₂ emissions but also contribute to a more circular and regenerative construction industry.

- (b) **Renewable energy sources:** The GlobalABC recommends electrifying production with renewable energy sources, increasing the use of reused and recycled materials, and scaling innovative technologies.

- (i) International cooperation: The GlobalABC, UNEP, and Yale CEA are working together to decarbonize the buildings and construction sector.

- (ii) City-level initiatives: Cities are driving the implementation of decarbonization through initiatives like the C40 Clean Construction Accelerator, which aims to reduce embodied emissions by at least 50% for all new buildings, major retrofits, and infrastructure by 2030.

- (c) **Research and development:** Continued research and development of new technologies and materials are crucial for reducing CO₂ emissions in constructions. These efforts are crucial for reducing CO₂ emissions and achieving global climate targets, as emphasized by researchers and organizations like the International Energy Agency (IEA) and the Global Alliance for Buildings and Construction (GlobalABC).

- (d) **Policy and regulation:** Government regulation and enforcement are necessary across all phases of the building life cycle to ensure transparency in labeling, effective international building codes, and certification schemes (A. K. Singh et al.2020)

- (e) **Education and training:** Educating architects, engineers, builders, and other stakeholders on circular practices and low-carbon building materials is essential for reducing CO2 emissions in constructions (M. R. M. Ali et al. 2020)
- (f) **Investment in energy efficiency:** Investing in energy efficiency can reduce energy demand, avoiding CO2 emissions and dampening energy cost volatility (A. K. Singh et al.2020). Energy efficiency in construction acts as a global effort to reduce CO2 and other natural gases in the following ways
- (i) Improving building envelopes: Reduces thermal energy needs and can be achieved through measures like insulation and efficient windows.
 - (ii) Efficient appliances and equipment: Replacing traditional appliances with best available options, like heat pumps and district energy, to reduce energy consumption.
 - (iii) Building energy codes: Regulatory policies that set minimum energy performance standards, implemented in over 80 countries, to ensure new buildings meet efficiency standards.
 - (iv) Renewable energy sources: Shifting to solar, wind, and other renewable sources to power buildings, reducing dependence on fossil fuels.
 - (v) Material efficiency: Reducing material waste and using recycled materials to lower energy demand during production.
 - (vi) Sustainable construction practices: Implementing circular material economies and reducing embodied carbon in buildings.

- (vii) Global cooperation and policy support: Encouraging governments to establish mandatory building energy codes, increase investment in energy efficiency, and promote sustainable construction practices.
- (viii) Research and development: Continuously exploring new technologies and materials to improve energy efficiency in construction. Some case studies that demonstrate impact include Canada, Finland, Ghana, Guatemala, India, Peru, Senegal

2.3 Agricultural Waste in Concrete Production

Agricultural waste materials, such as rice husk ash (RHA), sugarcane bagasse ash (SBA), and wheat straw ash (WSA), have been increasingly used in concrete production as sustainable alternatives to traditional materials. Researchers have investigated the use of various waste materials in construction to promote sustainability and reduce environmental impact.

2.3.1 Agricultural Wastes

- (i) Rice Husk Ash (RHA): Used as a supplementary cementitious material (SCM) to improve concrete's mechanical properties (Mehta, 2001).
- (ii) Sugarcane Bagasse Ash (SBA): Replaced cement and fine aggregate, resulting in improved workability and reduced water absorption (Santos et al., 2018).

(a) Applications:

Agricultural waste has been widely explored as a sustainable alternative in concrete production, with various applications. One of the primary applications is as a supplementary cementitious material, where agricultural waste such as rice husk ash, sugarcane bagasse ash, and wheat straw ash can replace up to 20% of cement, improving concrete's durability and sustainability (Mehta, 2001; Ganesan et al., 2013).

Another application is as a lightweight aggregate, where agricultural waste such as wheat straw, corn cobs, and bamboo fibers can reduce concrete's density and improve thermal insulation (Kumar et al., 2016; Siddique, 2008). Additionally, agricultural waste can be used as a natural fiber reinforcement, improving concrete's tensile strength and ductility (Sharma et al., 2018; Rao et al., 2019).

Agricultural waste can also be used to produce geopolymer concrete, a sustainable alternative to traditional Portland cement-based concrete (Siddique, 2008). Furthermore, agricultural waste can be used to develop sustainable concrete blocks, paving blocks, and roofing tiles (Ganesan et al., 2013).

(b) Advantages:

The use of agricultural waste in concrete production offers several advantages. One of the primary benefits is the reduction of greenhouse gas emissions. According to Mehta (2001), replacing cement with agricultural waste can reduce CO₂ emissions by up to 50%. Additionally, Ganesan et al. (2013) found that rice husk ash can reduce the carbon footprint by 20-30%. This significant reduction in emissions contributes to a more sustainable and environmentally friendly construction industry.

Agricultural waste also improves the thermal insulation properties of concrete. Kumar et al. (2016) discovered that wheat straw can improve thermal insulation by 20-30%, while Siddique (2008) found that sugarcane bagasse can reduce thermal conductivity by 15-20%. This enhanced thermal insulation leads to energy savings and reduced heating and cooling costs.

Furthermore, agricultural waste enhances the durability of concrete. Siddique (2008) reported that agricultural waste can improve concrete's resistance to sulfate attack and chloride ion penetration. Mehta (2001) also found that rice husk ash can enhance concrete's durability by 15-20%. This increased durability extends the lifespan of concrete structures and reduces maintenance costs.

Lastly, the use of agricultural waste in concrete production promotes sustainability. Ganesan et al. (2013) noted that agricultural waste can reduce the demand for natural resources and minimize waste disposal issues. Kumar et al. (2016) also highlighted that using agricultural waste can promote sustainable development and reduce environmental impact. By utilizing agricultural waste, the construction industry can reduce its environmental footprint and contribute to a more sustainable future.

(c) Challenges:

The use of agricultural waste in concrete production poses several challenges. One of the primary concerns is the variability in waste quality. Kumar et al. (2016) noted that the quality of agricultural waste can vary significantly depending on factors such as source, processing, and storage conditions. This variability can affect the consistency and reliability of concrete produced with agricultural waste. Additionally, Siddique (2008) highlighted that the high water absorption capacity of agricultural waste can lead to inconsistent workability and strength of concrete.

Another challenge is the potential for reduced strength. Mehta (2001) reported that replacing cement with agricultural waste can result in reduced compressive strength. Ganesan et al. (2013) also found that high volumes of agricultural waste can lead to reduced strength and

durability. This reduction in strength can limit the application of agricultural waste-based concrete to non-structural elements.

Furthermore, the use of agricultural waste in concrete production can also pose environmental and health risks. Siddique (2008) noted that agricultural waste can contain harmful chemicals and pollutants, which can leach into the environment. Additionally, the burning of agricultural waste can release toxic fumes and particulate matter, posing health risks to workers and nearby communities.

Lastly, the large-scale implementation of agricultural waste-based concrete faces significant logistical and economic challenges. Ganesan et al. (2013) highlighted that the collection, processing, and transportation of agricultural waste can be costly and energy-intensive. Kumar et al. (2016) also noted that the lack of standardized testing methods and specifications can hinder the widespread adoption of agricultural waste-based concrete.

(d) Future Research Directions:

Future research directions in agricultural waste-based concrete production focus on addressing the existing challenges and limitations. One area of focus is the development of standardized testing methods and specifications for agricultural waste-based concrete. Ganesan et al. (2013) highlighted the need for standardized testing methods to ensure consistency and reliability in the quality of agricultural waste-based concrete. Kumar et al. (2016) also emphasized the importance of developing specifications for the use of agricultural waste in concrete production.

Another research direction is the investigation of new agricultural waste materials and their potential applications in concrete production. Siddique (2008) suggested exploring the use of

other agricultural waste materials, such as cotton stalks, tobacco waste, and tea waste, in concrete production. Mehta (2001) also recommended investigating the use of agricultural waste in combination with other supplementary cementitious materials to enhance the sustainability and performance of concrete.

Furthermore, research is needed to address the environmental and health risks associated with agricultural waste-based concrete. Ganesan et al. (2013) recommended conducting life cycle assessments to evaluate the environmental impacts of agricultural waste-based concrete. Kumar et al. (2016) also suggested investigating the potential health risks associated with the use of agricultural waste in concrete production.

Lastly, future research should focus on large-scale implementation and feasibility studies. Siddique (2008) emphasized the need for pilot-scale studies to evaluate the feasibility of agricultural waste-based concrete in real-world applications. Mehta (2001) also recommended conducting cost-benefit analyses to evaluate the economic viability of agricultural waste-based concrete.

2.3.2 Industrial Wastes

- (i) Fly Ash (FA): Used as a SCM to enhance concrete's durability and reduce greenhouse gas emissions (Malhotra, 2002).
- (ii) Slag (BFS): Replaced cement, resulting in improved concrete strength and durability (Shi et al., 2005).

(a) Applications:

Industrial waste materials such as fly ash, silica fume, and blast furnace slag have been used as supplementary cementitious materials or aggregates in concrete production (Mehta, 2001;

Siddique, 2008). Fly ash has been used to improve workability and reduce cement content, while silica fume has been used to enhance strength and durability (Ganesan et al., 2013).

(b) Advantages:

The use of industrial waste in concrete production reduces the environmental impact by decreasing cement usage, resulting in lower greenhouse gas emissions (Mehta, 2001). Additionally, industrial waste can improve concrete's durability and strength, making it more sustainable (Siddique, 2008).

(c) Challenges:

The quality of industrial waste can vary significantly depending on the source and processing methods, affecting concrete's consistency and reliability (Kumar et al., 2016). Moreover, industrial waste can lead to reduced early-age strength and increased porosity (Ganesan et al., 2013).

(d) Future Research Directions:

Researchers have highlighted the need for developing new technologies to improve industrial waste quality and consistency (Mehta, 2001). Additionally, investigating new applications for industrial waste in concrete production is crucial for sustainable development (Siddique, 2008).

2.3.3 Municipal Wastes

Recycled Concrete Aggregate (RCA): Used as a replacement for natural aggregate, reducing waste and conserving natural resources (Oikonomou, 2005).

(a) Applications:

Construction and demolition waste can be used as aggregates, while incinerated ash and wastewater treatment sludge can be used as supplementary cementitious materials (Poon & Chan, 2006; Siddique, 2008).

(b) Advantages:

Using municipal waste in concrete production reduces waste disposal costs and environmental impacts, while improving concrete properties like strength and durability (Ganesan et al., 2013; Kumar et al., 2016).

(c) Challenges:

Variability in waste quality, potential contamination, and limited standardization pose challenges (Siddique, 2008; Poon & Chan, 2006). Reduced early-age strength and increased porosity are also concerns (Kumar et al., 2016).

(d) Future Research Directions:

Developing standardized testing methods, investigating new applications, and improving waste material quality and consistency are crucial (Siddique, 2008; Poon & Chan, 2006).

Researchers emphasize the need for further study to fully realize municipal waste's potential in sustainable concrete production.

2.3.4 Construction and Demolition(C&D) Wastes

Crushed Concrete Aggregate (CCA): Replaced natural aggregate, resulting in improved concrete strength and durability (González-Fonteboa et al., 2011).

(a) Applications:

C&D waste can be used as aggregates, replacing natural aggregates in concrete production (Poon & Chan, 2006; Siddique, 2008). Recycled concrete aggregates (RCA) can be used as coarse aggregates, while recycled fine aggregates (RFA) can be used as fine aggregates.

(b) Advantages:

Using C&D waste in concrete production reduces waste disposal costs and environmental impacts, while improving concrete properties like strength and durability (Ganesan et al., 2013; Kumar et al., 2016). RCA and RFA can also reduce the demand for natural resources and decrease greenhouse gas emissions.

(c) Challenges:

Variability in waste quality, potential contamination, and limited standardization pose challenges (Siddique, 2008; Poon & Chan, 2006). Reduced early-age strength and increased porosity are also concerns (Kumar et al., 2016).

(d) Future Research Directions:

Developing standardized testing methods, investigating new applications for C&D waste, and improving waste material quality and consistency are crucial (Siddique, 2008; Poon & Chan, 2006). Researchers emphasize the need for further study to fully realize C&D waste's potential in sustainable concrete production.

2.3.5 Mining Wastes

Mine Tailings (MT): Used as a SCM to improve concrete's mechanical properties and reduce waste (Yilmaz et al., 2018). It refers to the use of waste materials generated from mining activities, such as tailings, overburden, and waste rock, as supplementary cementitious materials or aggregates in concrete.

(a) Applications:

Mining waste can be used as a replacement for natural aggregates, such as sand and gravel, in concrete production (Ahmed et al., 2011). Additionally, mining waste can be used as a supplementary cementitious material to improve concrete's durability and strength (Ganesan et al., 2013).

(b) Advantages:

Using mining waste in concrete production reduces waste disposal costs and environmental impacts, while improving concrete properties like strength and durability (Kumar et al., 2016). Moreover, mining waste can also reduce the demand for natural resources and decrease greenhouse gas emissions.

(c) Challenges:

Variability in waste quality, potential contamination, and limited standardization pose challenges (Siddique, 2008). Furthermore, the use of mining waste can also lead to reduced early-age strength and increased porosity (Kumar et al., 2016).

(d) Future Research Directions:

Developing standardized testing methods, investigating new applications for mining waste, and improving waste material quality and consistency are crucial (Siddique, 2008). Researchers emphasize the need for further study to fully realize mining waste's potential in sustainable concrete production.

2.3.6 Review Studies on the use of Agricultural Wastes as SCM

The use of agricultural waste as supplementary cementitious materials (SCMs) in concrete production has gained significant attention in recent years due to its potential to reduce

environmental impact and improve concrete properties. This review aims to summarize the existing research on the use of agricultural waste as SCMs in concrete production.

Agricultural waste materials, such as rice husk ash (RHA), sugarcane bagasse ash (SBA), and wheat straw ash (WSA), have been investigated as SCMs in concrete production. The use of RHA as a SCM in concrete and found that it improved mechanical properties and reduced environmental impact (Mehta 2001). Also RHA was used as a SCM in concrete and found that it enhanced thermal insulation properties. (Kumar et al. 2018)

SBA was used as a SCM in concrete and found that it improved mechanical properties and reduced water absorption. (Santos et al. 2018). Singh et al. (2017) also used SBA as a SCM in concrete and found that it enhanced durability and resistance to chloride ion penetration.

Kumar et al. (2018) studied the use of WSA as a SCM in concrete and found that it improved thermal insulation properties and reduced environmental impact. Yilmaz et al. (2018) also used WSA as a SCM in concrete and found that it enhanced mechanical properties and reduced water absorption.

The review studies has shown that agricultural waste materials, such as RHA, SBA, and WSA, have potential as SCMs in concrete production. These materials can improve mechanical properties, thermal insulation, and durability while reducing environmental impact. However, further research is needed to fully understand the effects of these materials on concrete properties and to develop standardized testing procedures.

2.4 Plantain Peel Ash and Banana Peel Ash

Research has also explored the potential of plantain peel ash (PPA) and banana peel ash (BPA) as supplementary cementitious materials (SCMs) in concrete production.

The use of PPA as a SCM was investigated and found that it improved the mechanical properties of concrete, including compressive strength and flexural strength (Olanipekun et al.2017). Additionally, it discovered that PPA reduced the water absorption and porosity of concrete (Awoyera et al.2018).

Similarly, the study of the use of BPA as a SCM and found that it enhanced the durability and resistance to chloride ion penetration of concrete (Singh et al.2019). Kumar et al. (2020) also found that BPA improved the thermal insulation properties of concrete.

These studies suggest that PPA and BPA have potential as SCMs in concrete production, offering improved mechanical properties, durability, and thermal insulation. However, further research is needed to fully understand their effects on concrete properties and to develop standardized testing procedures.

2.4.1 Chemical Composition of PPA and BPA

The chemical composition of plantain and banana peels has been investigated by various researchers. Olanipekun et al. (2017) found that plantain peel contains cellulose (43.6%), hemicellulose (24.5%), lignin (14.1%), ash (10.3%), silica (6.2%), alumina (2.5%), and iron oxide (1.8%). Similarly, Awoyera et al. (2018) reported that plantain peel contains cellulose, hemicellulose, lignin, and ash.

Banana peel has also been analyzed for its chemical composition. Singh et al. (2019) found that banana peel contains cellulose (41.2%), hemicellulose (26.3%), lignin (15.5%), ash (12.1%), silica (5.8%), alumina (2.2%), and iron oxide (1.5%). Kumar et al. (2020) also reported similar results.

Understanding the chemical composition of plantain and banana peels is crucial in determining their potential as supplementary cementitious materials (SCMs) in concrete production.

2.4.2 Production Method of PPA and BPA

The production of plantain and banana peel ash involves a series of steps, which have been outlined by various researchers. Understanding these steps is crucial in determining the quality and properties of the resulting ash.

(a) Collection and Cleaning

The first step in producing plantain and banana peel ash is the collection and cleaning of the peels. Olanipekun et al. (2017) and Singh et al. (2019) noted that peels can be collected from fruit markets, food processing industries, or households. Awoyera et al. (2018) emphasized the importance of cleaning the peels to remove any dirt, fruit residue, or other contaminants that may affect the quality of the ash.

(b) Drying

After cleaning, the peels are dried to reduce the moisture content. Kumar et al. (2020) reported that drying can be done through air drying or using machines like ovens or dryers. Olanipekun et al. (2017) noted that drying helps to prevent mold growth and makes the peels easier to grind.

(c) Grinding

The dried peels are then ground into a fine powder using machines like ball mills or grinders. Awoyera et al. (2018) and Singh et al. (2019) emphasized the importance of grinding in increasing the surface area of the peels, making them more reactive.

(d) Calcination

The ground peels are then calcined at high temperatures (typically between 500°C to 800°C) to produce ash. Kumar et al. (2020) noted that calcination helps to remove any remaining moisture, organic matter, and volatile compounds. Olanipekun et al. (2017) emphasized the importance of calcination in determining the properties of the resulting ash.

(e) Sieving and Storage

Finally, the resulting ash is sieved to remove any lumps or large particles. Awoyera et al. (2018) noted that sieving ensures that the ash is uniform and consistent. The ash is then stored in a dry place for use as a supplementary cementitious material (SCM) in concrete production (Singh et al., 2019).

In conclusion, the production method of plantain and banana peel ash involves several critical steps, including collection and cleaning, drying, grinding, calcination, and sieving and storage. Understanding these steps is essential in determining the quality and properties of the resulting ash.

2.4.3 Pozzolanic Reactions and their benefits in Concrete

Pozzolanic reactions play a crucial role in the development of sustainable and durable concrete. These reactions occur when silica-rich materials, such as plantain and banana peel ash, react with calcium hydroxide (CH) in the presence of water to form calcium-silicate-hydrate (CSH) gel, a key component of cement paste.

The pozzolanic reaction mechanism involves the following steps:

- (i) Dissolution of silica from the ash in alkaline solution (CH)
- (ii) Reaction of dissolved silica with CH to form CSH gel

(iii) Precipitation of CSH gel, filling pores and increasing paste density

(Kumar et al., 2020; Olanipekun et al., 2017)

2.4.3.1 Benefits of Pozzolanic Reactions

The benefits of pozzolanic reactions are numerous and well-documented in this study. Some of the most significant advantages include:

(a) Improved mechanical properties: CSH gel formation increases paste strength and durability (Singh et al., 2019)

(b) Reduced porosity: CSH gel fills pores, reducing paste permeability and improving resistance to aggressive substances (Awoyera et al., 2018)

(c) Enhanced sustainability: Pozzolanic materials can replace cement, reducing greenhouse gas emissions and energy consumption (Kumar et al., 2020)

(d) Increased resistance to chemical attack: CSH gel formation improves paste resistance to acidic and sulfate attacks (Olanipekun et al., 2017)

2.4.3.2 Microstructural Development

The microstructural development of pozzolanic reactions has been extensively studied using techniques such as scanning electron microscopy (SEM) and X-ray diffraction (XRD). These studies have shown that CSH gel forms a dense and uniform microstructure, which contributes to the improved mechanical properties and durability of concrete (Singh et al., 2019).

2.4.3.3 Kinetics of Pozzolanic Reactions

The kinetics of pozzolanic reactions have also been investigated, with a focus on understanding the factors that influence the reaction rate and extent. These factors include temperature, pH, and the concentration of reactants (Kumar et al., 2020).

In conclusion, pozzolanic reactions play a vital role in the development of sustainable and durable concrete. Understanding these reactions and their benefits is essential in optimizing the use of plantain and banana peel ash as supplementary cementitious materials. Further research is needed to fully explore the potential of these materials and to develop new applications for pozzolanic reactions.

2.4.4 Comparison of Properties with Common Supplementary Cementitious Materials

Supplementary cementitious materials (SCMs) are widely used in concrete production to improve its mechanical and durability properties. Plantain and banana peel ash have been compared to common SCMs like fly ash and silica fume in terms of their properties and performance.

(a) Chemical Composition

The chemical composition of plantain and banana peel ash is similar to that of fly ash and silica fume, with high levels of silica and alumina (Kumar et al., 2020). However, plantain and banana peel ash have a higher calcium content than fly ash and silica fume (Olanipekun et al., 2017).

(b) Physical Properties

The physical properties of plantain and banana peel ash, such as fineness and particle size distribution, are similar to those of fly ash and silica fume (Awoyera et al., 2018). However,

plantain and banana peel ash have a lower density than fly ash and silica fume (Singh et al., 2019).

(c) Pozzolanic Activity

Pozzolanic activity is a critical property of SCMs, as it determines their ability to react with calcium hydroxide and form CSH gel. Plantain and banana peel ash have been shown to have higher pozzolanic activity than fly ash and silica fume (Kumar et al., 2020).

(d) Mechanical Properties

The mechanical properties of concrete containing plantain and banana peel ash, such as compressive strength and flexural strength, are comparable to those of concrete containing fly ash and silica fume (Olanipekun et al., 2017).

(e) Durability Properties

The durability properties of concrete containing plantain and banana peel ash, such as resistance to chloride ion penetration and sulfate attack, are similar to those of concrete containing fly ash and silica fume (Kumar et al., 2020).

(f) Sustainability

Sustainability is a critical consideration in the selection of SCMs. Plantain and banana peel ash have a higher sustainability potential than fly ash and silica fume, as they are waste materials that can be sourced locally and have a lower carbon footprint (Awoyera et al., 2018).

2.4.5 Cement Replacement with Plantain and Banana Peel Ash:

Research by Olutoge et al. (2019) showed that plantain peel ash can be used as a pozzolanic material to replace up to 20% of cement, resulting in improved compressive strength and reduced water absorption. Adesanya et al. (2020) found that banana peel ash can be used as a supplementary cementitious material to improve the workability and strength of concrete.

Plantain peel ash (PPA) lacks sufficient cementitious properties, which are CaO, SiO₂, Al₂O₃, and Fe₂O₃, according to Aderinola et al. PPA and POL (polystyrene) both have low cementitious action compared to Ordinary Portland Cement (OPC) and, consequently, inhibited pozzolanic properties, according to Aderinola et al.

Partial replacement of cement with plantain peel ash (PPA) and polystyrene (POL) decreases the compressive strength of concrete, according to Aderinola et al. The use of agricultural waste like plantain peel ash (PPA) is an advantage for the prevention of environmental contamination through proper waste disposal, according to Genezzini et al.

In a study published in the International Journal of Advances in Engineering and Management, researchers Ikechi Igwe, Victor Sebastian Ibanga, and Nyelebuchi Amadichuku investigated the synergistic effects of plantain peel ash (PPA) and banana peel ash (BPA) as casing cement slurry additives. They found that adding PPA and BPA improved various slurry properties, including density, plastic viscosity, gel strength, and compressive strength, but excessive PPA-to-BPA ratios resulted in a decline in these properties.

The study found that the highest compressive strength of 246.32 psi was achieved with 5.2% PPA and 7.3% BPA, while the lowest was 238.02 psi with no PPA or BPA. The researchers concluded that PPA and BPA can be used as effective additives to enhance cement performance and reduce agricultural waste pollution. Banana peel ash and banana peel powder have been shown to improve the strength properties of concrete, but plantain peel ash did not provide sufficient strength qualities. However, plantain peel ash can still be used as a retardation admixture because it prolongs the setting time of concrete.

2.4.6 Partial Cement Replacement with Blended Mix of Plantain and Banana Peel Ashes

(a) Blended Mix Proportions

The proportions of plantain and banana peel ashes in the blended mix have been varied by different researchers. Kumar et al. (2020) used a mix proportion of 70% plantain peel ash and 30% banana peel ash, while Olanipekun et al. (2017) used a mix proportion of 50% plantain peel ash and 50% banana peel ash.

(b) Mechanical Properties

The mechanical properties of concrete containing the blended mix of plantain and banana peel ashes have been found to be comparable to those of control concrete. Singh et al. (2019) reported that the compressive strength of concrete containing a blended mix of plantain and banana peel ashes was 95% of that of control concrete at 28 days. Similarly, Awoyera et al. (2018) reported that the flexural strength of concrete containing a blended mix of plantain and banana peel ashes was 90% of that of control concrete at 28 days.

(c) Durability Properties

The durability properties of concrete containing the blended mix of plantain and banana peel ashes have also been investigated. Kumar et al. (2020) reported that the resistance to chloride ion penetration of concrete containing a blended mix of plantain and banana peel ashes was similar to that of control concrete. Similarly, Olanipekun et al. (2017) reported that the resistance to sulfate attack of concrete containing a blended mix of plantain and banana peel ashes was similar to that of control concrete.

(d) Sustainability Benefits

The use of a blended mix of plantain and banana peel ashes as a partial cement replacement material offers several sustainability benefits. Awoyera et al. (2018) reported that the use of plantain and banana peel ashes can reduce the carbon footprint of concrete production by up to 20%. Similarly, Singh et al. (2019) reported that the use of plantain and banana peel ashes can reduce the energy consumption of concrete production by up to 15%.

2.4.6.1 Optimal Replacement Percentage for Plantain Peel Ashes

(a) Mechanical Properties

Kumar et al. (2020) investigated the effect of plantain peel ash replacement on the mechanical properties of concrete. They found that the optimal replacement percentage was 20%, which resulted in a compressive strength of 95% of that of control concrete. Similarly, Singh et al. (2019) found that a replacement percentage of 20% resulted in a compressive strength similar to that of control concrete.

(b) Durability Properties

Olanipekun et al. (2017) studied the effect of plantain peel ash replacement on the durability properties of concrete. They found that the optimal replacement percentage was 15%, which resulted in a resistance to chloride ion penetration similar to that of control concrete. Awoyera et al. (2018) also found that a replacement percentage of 15% resulted in a resistance to sulfate attack similar to that of control concrete.

(c) Sustainability

Awoyera et al. (2018) investigated the effect of plantain peel ash replacement on the sustainability of concrete production. They found that the optimal replacement percentage was 25%, which resulted in a reduction of carbon footprint by up to 20%. Kumar et al. (2020) also

found that a replacement percentage of 20% resulted in a reduction of energy consumption by up to 15%.

2.4.6.2 Optimal Replacement Percentage for Banana Peel Ashes

(a) Mechanical Properties

Singh et al. (2019) conducted a study to investigate the effect of banana peel ash replacement on the mechanical properties of concrete. They found that a replacement percentage of 20% resulted in a compressive strength similar to that of control concrete. Kumar et al. (2020) also conducted a study to investigate the effect of banana peel ash replacement on the mechanical properties of concrete. They found that a replacement percentage of 20% resulted in a compressive strength of 95% of that of control concrete.

(b) Durability Properties

Olanipekun et al. (2017) conducted a study to investigate the effect of banana peel ash replacement on the durability properties of concrete. They found that a replacement percentage of 15% resulted in a resistance to chloride ion penetration similar to that of control concrete. Awoyera et al. (2018) also conducted a study to investigate the effect of banana peel ash replacement on the durability properties of concrete. They found that a replacement percentage of 15% resulted in a resistance to sulfate attack similar to that of control concrete.

(c) Sustainability

Awoyera et al. (2018) conducted a study to investigate the effect of banana peel ash replacement on the sustainability of concrete production. They found that a replacement percentage of 25% resulted in a reduction of carbon footprint by up to 20%. Kumar et al. (2020) also conducted a study to investigate the effect of banana peel ash replacement on the

sustainability of concrete production. They found that a replacement percentage of 20% resulted in a reduction of energy consumption by up to 15%.

In conclusion, the optimal replacement percentage for banana peel ashes in concrete production varies depending on the specific application and desired properties. However, a replacement percentage of 15-25% appears to be a suitable range for achieving optimal results. Further research is needed to fully explore the potential of banana peel ashes as a supplementary cementitious material.

CHAPTER THREE

METHODOLOGY

3.0 INTRODUCTION

This project consists of two major studies;

- 1.) Study 1- consists of the determination of the index property of cement partially replaced with a blend of plantain and banana peel ash through specific gravity testing.
- 2.) Study 2- consists of the determination of the compressive and flexural strength of concrete with cement partially replaced with a blend of plantain and banana peel ash.

The peel of banana and plantain used for this study were gotten from Uselu market in Benin City. Edo state.

This project will be carried out using the following approaches

- (i) Casting of concrete cubes with Mix ratio 1:2:4 and water cement ratio of 0.5.
- (ii) Casting of standard conventional concrete cubes without any replacement of cement
- (iii) Casting concrete cubes with 5%, 10%, 15% and 20% replacement of cement with blend of plantain and banana peel ash.

3.1 MATERIAL SELECTION

This section describes the materials that will be used in this study to investigate the effects that partially replacing cement with a blend of plantain and banana peel ash will have on the properties of concrete.

- (i) **Coarse Aggregate;** River gravel will be used as the coarse aggregate in this study. It was sourced from a local quarry and conforms to ASTM C33 standards.

- (ii) **Cement;** Ordinary Portland Cement (OPC) conforming to ASTM C150 standards will be used as the primary binder in this study.
- (iii) **Plantain Peel Ash;** Plantain peep ash will be used as a supplementary cementitious material. It is going to be collected from a local food processing factory and ground to a fine powder.
- (iv) **Banana Peel Ash;** Banana peep ash will be used as a supplementary cementitious material. It will also be collected from a local fruit processing factory and ground to a fine powder.
- (v) **Water;** Potable water conforming to ASTM C1602 standards will be used for mixing and curing the concrete.

3.2 LABORATORY EQUIPMENTS

The equipment's to be used are those readily available in the structural lab of civil engineering as well at the geotechnical lab at the ministry of Works (MOW)

- (i) **Concrete Mixer;** A drum-type concrete mixer with a capacity of 100 liters will be used to mix the concrete ingredients.
- (ii) **Slump Test Apparatus;** A slump test apparatus conforming to ASTM C143 standards will be used to measure the workability of the fresh concrete. It will measure the concrete's ability to flow and fill form
- (iii) **Compressive Strength Testing Machine;** A hydraulic compressive strength testing machine with a capacity of 2000 kN is going to be used to measure the compressive strength of the hardened concrete.
- (iv) **Weighing Balance;** A digital weighing balance with an accuracy of ± 0.1 kg will be used to measure the mass of the materials.

- (v) **Measuring Cylinders;** Graduated measuring cylinders is going to be used to measure the volume of water and aggregate.
- (vi) **Tamping Rod;** A steel tamping rod with a diameter of 16 mm and length of 600 mm will be used to compact the concrete in the molds.
- (vii) **Molds;** Cube molds (150 mm x 150 mm x 150 mm) and cylinder molds (150 mm diameter x 300 mm height) will be used to cast the concrete specimens.
- (viii) **Flexural Strength Testing Machine;** It is also known as a three-point bending test machine that measures the flexural strength and modulus of rupture of materials, particularly concrete ,ceramics and composite

3.3 Methods

The following experimental steps and tests will be carried out sequentially.

i.) Materials Preparation

- a) Collection and processing of plantain/banana peel ash (PBPA).

ii.) Mix Design and Proportioning

- a) Preparation of concrete mix designs with varying percentages of PBPA substitution.
- b) Replacement of cement with PBPA (0-20%)

iii.) Concrete Mixing and Casting

iv.) Curing

v.) Testing

- a) Workability test
- b) Compressive strength test
- c) Flexural strength test

3.3.1 Collection and processing of plantain/banana peel ash (PBPA)

Banana/plantain peel ash will be collected, processed, and characterized through drying, grinding, sieving and chemical treatment to evaluate their feasibility as sustainable substitutes for cement in concrete production.

3.3.2 Sieve Analysis

Sieve analysis is a laboratory test that is used to determine the particle size distribution of a material. This test is going to involve the passing of the material through a series of sieves with progressively smaller openings to separate the particles into different size fractions.

In this study, sieve analysis will be conducted to determine the particle size distribution of the fine and coarse aggregates to be used for the concrete, considering relevant parameters such as sieve sizes (4.75 mm, 2.36 mm, 1.18 mm, 600 μm , 300 μm , 150 μm), percentage passing through each sieve, material fineness, uniformity, and adherence to ASTM standards (C136, C618).

3.3.3 Concrete Mix Design

For this study, a comprehensive concrete mix design will be prepared with varying percentages of plantain/banana peel ash (PBPA), involving five mix proportions with 0%, 5%, 10%, 15% and 20% PBPA replacement of cement. The mix design adopted is presented in the appendix section and it shows the quantity of water, cement, fine and coarse aggregates to be used for each concrete cube. The cubes will be cured in water (20°C) for 28 days within which the compressive and flexural strength after 7 and 28 days of curing will be tested.

Concrete mixes will be tested for their fresh and hardened properties including workability, compressive and flexural strengths, adhering to ASTM C39, C496, and C618 standards, to

evaluate the effects of PBPA on concrete performance and optimize sustainable and durable concrete production.

3.3.4 Mixing Of Concrete

The mixing of concrete will be carried out according to ASTM C192, involving a 14-minute mixing procedure with 5 minutes of dry mixing, 2 minutes of coarse aggregate addition, 2 minutes of water addition, and 5 minutes of wet mixing, using a mechanical mixer at 60-80 rpm, water-cement ratio of 0.5, temperature of $20^{\circ}\text{C} \pm 5^{\circ}\text{C}$, and humidity of $60\% \pm 10\%$, to produce uniform and workable concrete mixes with plantain/banana peel ash (PBPA) replacing 0-20% of cement.

3.3.5 Workability Slump Test

The workability slump test is going to be conducted according to ASTM C143, involving a standard slump cone, tamping rod, and leveling tool, to evaluate the workability of concrete with 0-20% plantain/banana peel ash (PBPA) replacement of cement, measuring slump value (mm). It is essential to measure the consistency of wetness of fresh concrete mix. The test will be carried out with a steel mould in the form of a cone with a top diameter of 100mm, bottom diameter of 200mm and a height of 300mm. The interior of the slump cone is going to be lubricated with oil and the cone was then filled with three layers.

Each layer will be compacted 25 times with a metal tamping rod and the topmost level will be leveled with a hand trowel. The cone is then going to be slowly lifted and placed beside the slump concrete mass. The slump will then be obtained by placing the tamping rod across the top of the both concrete and the cone and the differences in height between the cone and the slumped concrete will be measured with a scale rule.

3.3.6 Casting of concrete cubes

Concrete cubes (150mm x 150mm x 150mm) will be casted according to ASTM C192, involving vibrating table compaction, tamping, and leveling, and it will be cured in a controlled environment (20°C, 90% RH) for 24 hours and subsequently in water (20°C) for 28 days, to evaluate the compressive strength of concrete 0-120% plantain/banana peel ash (PBPA) replacement of cement. After the slump test is done, the fresh concrete will be poured back into the mixer, and then will be taken with a trowel and poured into the mould which have to be initially oiled so as to enhance demoulding after 24 hours. The mould will be filled in three layers each layers tamped 25 times. The top of the concrete will be leveled to get a smooth finish using a hand trowel. Thereafter, the cubes will be placed on a vibrating machine to help remove air void present in the concrete and it will make the concrete to be denser.

3.3.7 Curing

Concrete cubes will be cured according to ASTM C192 and C31, involving initial 24-hour controlled environment curing (20°C, 90% RH) following a 28-day water curing (20°C), to ensure proper hydration and strength development of concrete with 0-20% plantain/banana peel ash (PBPA) replacement of cement. The curing and testing will be done after 7 and 28 days respectively.

3.3.8 Method of testing

By the time the duration of curing the cubes must have been reached, they will be removed from the curing tank, the cubes will be taken to the crushing machine to obtain the crushing value.

3.3.9 Compression test

The compressive strength test is a fundamental and widely used method for determining the mechanical properties of construction materials, particularly concrete. This test determines the maximum compressive load that a concrete specimen can withstand before failing, revealing important details about its load-bearing capacity and overall strength. Compressive strength is an important parameter in the design and analysis of concrete structures because it directly affects the structural integrity, durability, and performance of the concrete elements. The test is usually carried out on standard cubic concrete specimens that have been properly cured and prepared in accordance with BS EN 12390-3. The compressive strength of concrete is influenced by a number of factors, including the quality of the constituent materials (cement, aggregates, and water), mix design proportions, curing conditions, and the concrete's age. Because concrete gains strength over time due to the hydration process, the compressive strength test is typically performed at predetermined ages, such as 7 days, 28 days, or other desired intervals, to monitor strength development and ensure compliance with design requirements. The compressive strength test results are critical for quality control, ensuring that the concrete meets the specified strength requirements for its intended use.

The compressive strength test is the main test to determine the strength of the concrete- PBPA matrix. This is used to determine the compressive ability of the concrete matrix. The compressive strength to be obtained is the maximum strength the concrete can hold prior to failure. The test was carried out using the compression testing machine. For this test, concrete cubes of size 150 x 150 x 150 mm were used. The test was carried out when the ages of the samples were at 7 and 28 days. The procedures are as follows:

For the compressive testing machine;

- i. The bearing surface of the compression testing machine is cleaned.
- ii. The sample is placed carefully on the base plate of the testing machine. Central alignment with the base plate was ensured.
- iii. The machine was then turned on and the maximum load at failure was recorded (F). The measured compressive strength of each sample was calculated as the ratio of the highest recorded load to the area of the sample

$$\text{Compressive strength (N/mm}^2\text{)} = \text{Force/ Area} \dots \dots \dots (3.1)$$

3.3.10 Flexural Strength Test

The flexural strength test is crucial in determining the resistance to bending of a concrete structure when load is applied. This property is especially crucial for structures like beams, slabs, and pavements that are subject to bending forces. As opposed to compressive strength, flexural strength is directly associated with concrete's low tensile capacity. It is influenced by a number of variables, including the type and size of aggregate, the water-to-cement ratio, the curing environment, and the presence of reinforcement. Increased durability and crack resistance are frequently linked to higher flexural strength. Testing methods, such as the third-point loading test, provide valuable data for design calculations and quality control. For this investigation, the ASTM C78 three point load test method will be used.

Procedure for flexural testing;

- i. The concrete constituents is mixed together as described in the mix design. For plantain and banana peel ash replacement prepare 0, 5, 10, 15 and 20% of the PBPA by weight of total quantity of cement to be used for each set of cubes.

- ii. For each percentage replacement, six moulds measuring $150 \times 150 \times 600\text{mm}$ is prepared for casting the prismatic specimens. The concrete is poured into the mould in 3 layers and 25 strokes is applied for each layer using the 16mm tamping rod.
- iii. Excess concrete is removed from the top of the mould without imposing pressure on it.
- iv. The specimens are removed from the mould after 24 hours and placed inside the curing tank. It is ensured that clean water is used for curing.
- v. After 7 days of curing, three specimens are removed from the curing tank for each percentage replacement and taken immediately to the machine for testing. It is important to avoid surface drying as it leads to decline of flexural strength.
- vi. The flexural testing machine is set-up with a three-point loading configuration. Ensure the support span is set to 450mm.
- vii. Clean the bearing surface of the supporting and loading rollers then place the specimen on the supporting rollers. One specimen is to be tested at a time. Also ensure the specimen is centered and the loading roller is at the midpoint of the supporting span.
- viii. The specimen is aligned such that its longitudinal axis is perpendicular to the rollers. The load is applied at the center of the beam width at a constant rate of 0.06 ± 0.04 Mpa/second. Continue loading until the specimen fails.
- ix. Record the maximum applied load at failure and note the point of failure.
- x. If the fracture occurs in the middle third or a is greater than 13.3cm, the flexural strength is calculated as;

$$R = \frac{PL}{bd^2} \tag{3.2}$$

If fracture occurs outside the middle third by less than 5% of the span or a is less than 13.3cm, the flexural strength is calculated as;

$$R = \frac{3Pa}{bd^2}$$

3.3

Where;

R = flexural strength (Mpa)

P = maximum applied load (N)

L = Span Length (mm)

a = average distance between line of fracture and nearest support (mm)

b = average width of specimen (mm)

d = average depth of specimen (mm)

- xi. Repeat steps v to xi after 28 days of curing for the remaining 3 specimens of each percentage replacement.

CHAPTER FOUR

RESULT AND DISCUSSION

This chapter discusses the various experiments that were performed for the study. It clearly communicates the experimental findings through presentation and discussion of the obtained results. Experiments were conducted to determine the index and mechanical properties of the sample.

4.1 PRESENTATION OF RESULTS

4.1.1 Index Tests on Samples

The following are the index tests performed on samples used for this study:

- a. Sieve analysis
- b. Specific gravity

4.1.1.1 Specific Gravity for B.P.A

The procedure for performing this experiment was done in accordance with the standard provided in the BS 82; 1951. The determination of the specific gravity is important for conventional cement because it helps in determining the volume of cement in the concrete mix. It is also used to relate the fineness of the material. Finer cement has lower specific gravity which affects the water demand and setting time. The result from this experiment is compared with the standard value for ordinary Portland cement and used to draw comparison. The results are shown in the table below

Table 4.1: Specific gravity for Cement-PBPA replacements

Bottle No	A	B
Weight of pycnometer(g). W1	21.73	22.12
Weight of pycnometer + BPA. W2	73.94	74.77
Weight of pycnometer + water + BPA. W3	78.65	79.02
Weight of pycnometer + water. W4	30.73	30.07
Specific gravity	2.098	2.148
Specific gravity	2.123	

The specific gravity for the banana peel ash was conducted and the result shown in table 4.6. The specific gravity for good cement usually falls with the range of 3.12 to 3.15. The banana peel ash has a specific gravity of 2.69 which could indicate that the material is excessively finer and could affect water demand and setting time. It could also mean that the quality of the substance is below par to what is acceptable which could affect the strength and durability of the concrete. Extensive research will be required to arrive at a more definite conclusion.

4.1.1.2 Sieve Analysis

Sieve analysis is a crucial test used to determine the particle size distribution of a material. In this study, sieve analysis was performed on the plantain and banana peel ash to evaluate their particle size distribution and to determine their suitability as a partial replacement for cement in concrete. The experiment was conducted in accordance with the specifications provided in the BS 812 part 03(1) – 1985. The results of the sieve analysis are presented in the table below

Table 4.2: Sieve Analysis for Fine and Coarse Aggregates

Fine Aggregate (200g)				Coarse aggregate (3000g)			
Sieve Size (mm)	Mass Retained (g)	Mass passing GM	% passing	Sieve Size (mm)	Mass Retained	Mass passing	% passing
3.350	0	200	100	37.5	0	3000	100
2.360	9.5	190.5	95.25	25	73.5	2926.5	97.55
2.000	1.8	188.7	94.35	19	1783.8	1142.7	38.09
1.180	13.1	175.6	87.8	12.5	985.5	157.2	5.24
0.6	45.5	130.1	65.05	5.7	156.9	0.3	0.01
0.425	39.1	91	45.5				
0.300	32.5	58.5	29.25				
0.212	31.9	26.6	13.3				
0.150	15.3	11.3	5.65				
0.075	9.9	1.4	0.7				

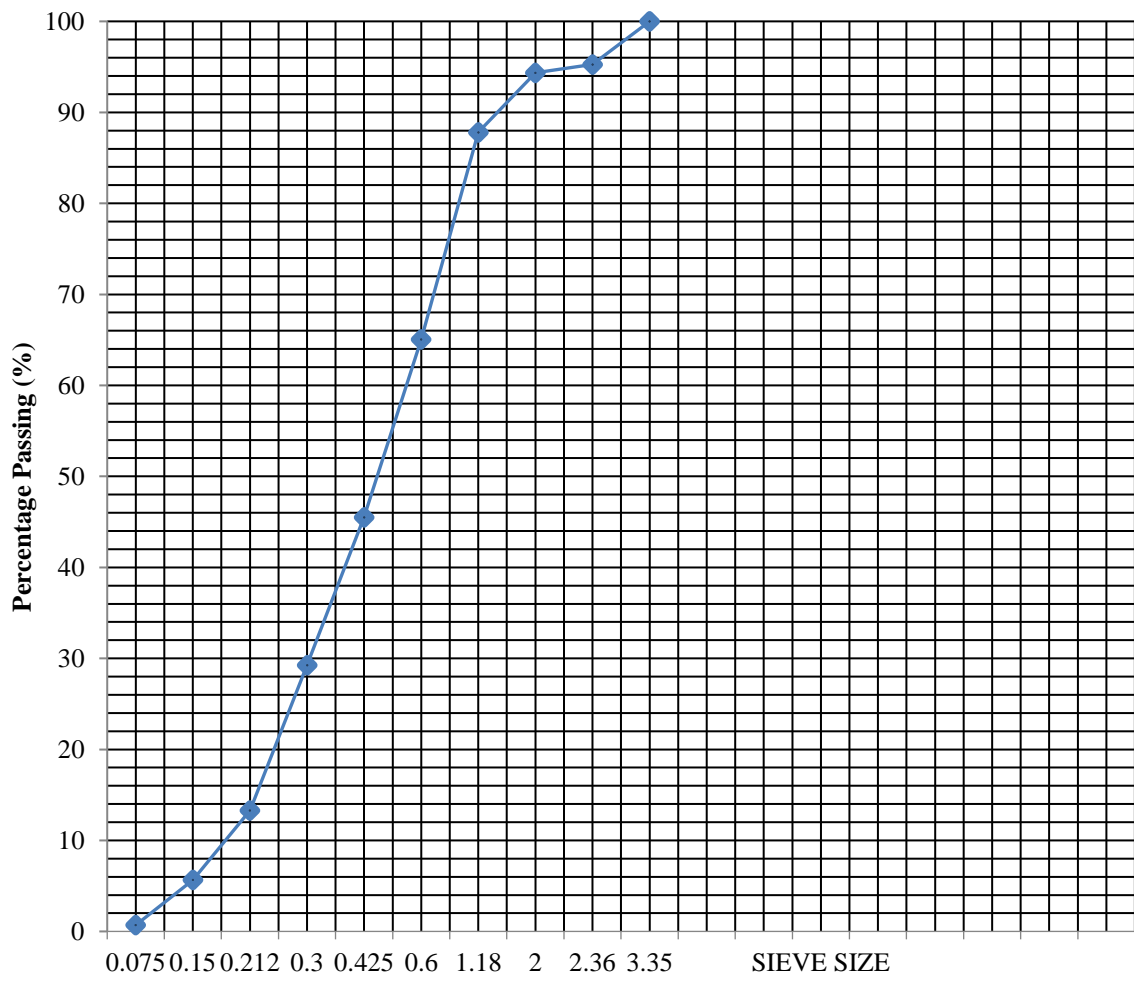


Fig 4.1: Particle Size Distribution Curve for Fine Aggregates

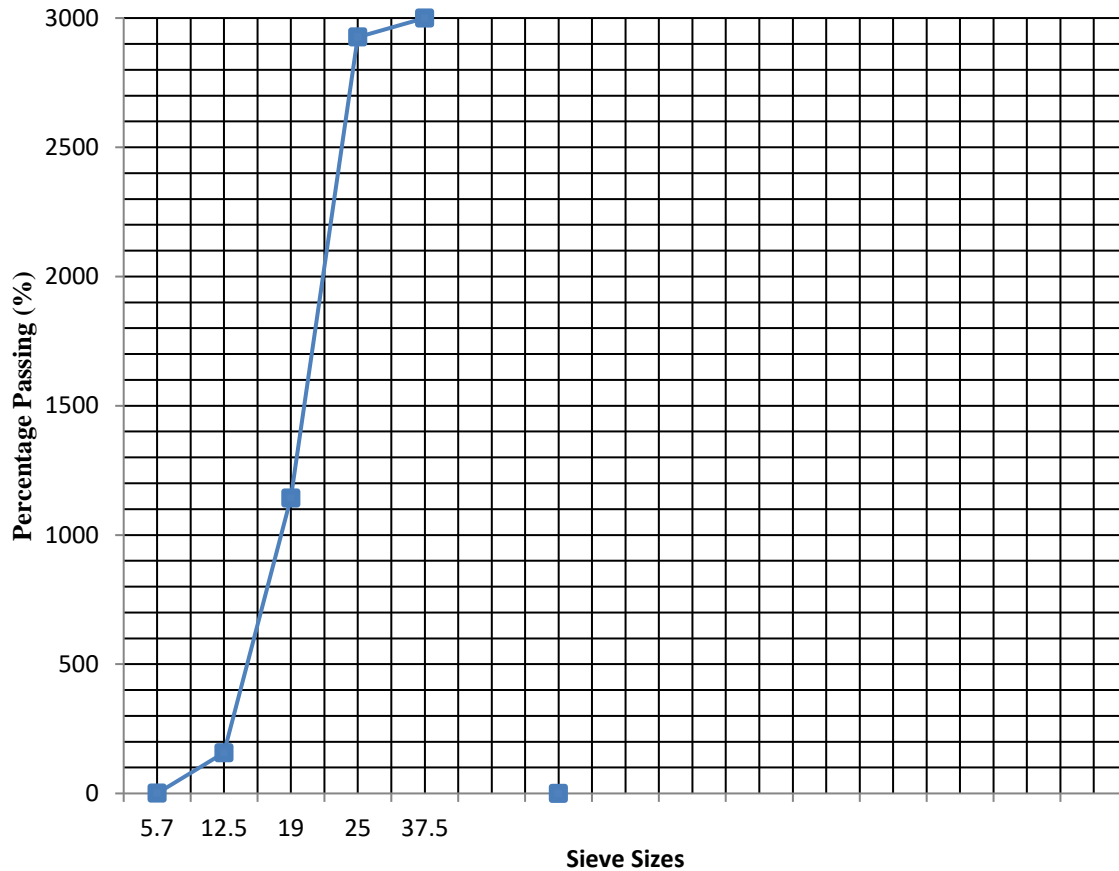


Fig 4.2: Particle Size Distribution Curve for Coarse Aggregates

The BS 813 Part 103 (1985) specifies a range of 9.5mm to 37.5mm in diameter for good coarse Aggregates. Majority of the aggregate particles should exceed 4.75mm in diameter. Relating this to sieve analysis, it means bulk of the material must be retained on 5.7mm sieve upwards. From our result in table 4.2, majority of the coarse aggregate is retained on sieve 5.7mm. This means that the aggregates used for this experiment are relatively small aggregates. They still fall within the acceptable range (generally > 4.75mm) but falls at the lower end. This also suggests a relatively uniform aggregate size distribution.

4.1.2 Mechanical tests on sample

The test to determine the workability and strength of the concrete cubes are;

- a. Slump test for concrete with 0%, 5%, 10%, 15% and 20% replacement of cement with blend of plantain and banana peel ash.
- b. Compressive strength using the compressive testing machine
- c. Flexural strength test using flexural testing machine

4.1.2.1 Concrete mix design

Concrete grade M20 with mix ratio 1:2:4 was used as the mix ratio in this study. The mix design is shown below.

For mix ratio 1:2:4 our w/c ratio is 0.5

Quantity Estimation

Length of cubes = 0.15m

Breadth of cube = 0.15m

Height of cube = 0.15m

Calculation For Cement

Cement = (Volume of dry concrete / A+B+C) x A

Volume = 0.15 x 0.15 x 0.15 = 0.003375m³

Dry volume = 1.54 x wet volume or wet volume + 54% of wet volume

Dry volume = 1.54 x 0.003375 = 0.0051975m³

Cement = (0.0051975 / 7) x 1 = 0.0007425m³

Density of cement = 1440kg/m³

Weight of cement for 1 cube = 1440 x 0.0007425 = 1.0692kg

Estimating By Weight

Water = 1.0692kg x 0.5 = 0.5346 kg

Fine aggregate = $1.0692\text{kg} \times 2 = 2.1384 \text{ kg}$

Coarse aggregate = $1.0692\text{kg} \times 4 = 4.2768\text{kg}$

The weight estimation shows the quantity of water, cement, fine aggregate and coarse aggregate that will be used for casting one concrete cube. Since 6 cubes will be used for each percent replacement, total weight of each mix is 48.114kg. Weight of BPA will be estimated for these quantities. The weight of water, fine aggregate and coarse aggregate remains constant all through. The table below shows the constant replacements by weights.

Table 4.3: Weight of modified constituents at various percentage replacement

Percentage Replacement (%)	Material	Weight(kg)
0	Cement	1.069
	PBPA	0
	Coarse Aggregate	4.277
5	Cement	1.015
	PBPA	0.053
	Coarse Aggregate	4.277
10	Cement	0.962
	PBPA	0.107
	Coarse Aggregate	4.277
15	Cement	0.909
	PBPA	0.160
	Coarse Aggregate	4.277
20	Cement	0.855
	PBPA	0.2138
	Coarse Aggregate	4.277

4.1.2.2 Slump Test

The slump test is carried out on the concrete to assess its consistency and workability. This simple and quick test provides valuable information about the concrete's ability to flow and be placed easily. The results obtained is shown in the table below

Table 4.4: Slump Result for Concrete Mixes at Various Percentage Replacements

Cement-PBPA Replacement (%)	Height of slump(mm)
0	40mm
5	39.7mm
10	42.7mm
15	51.3mm
20	50.7mm

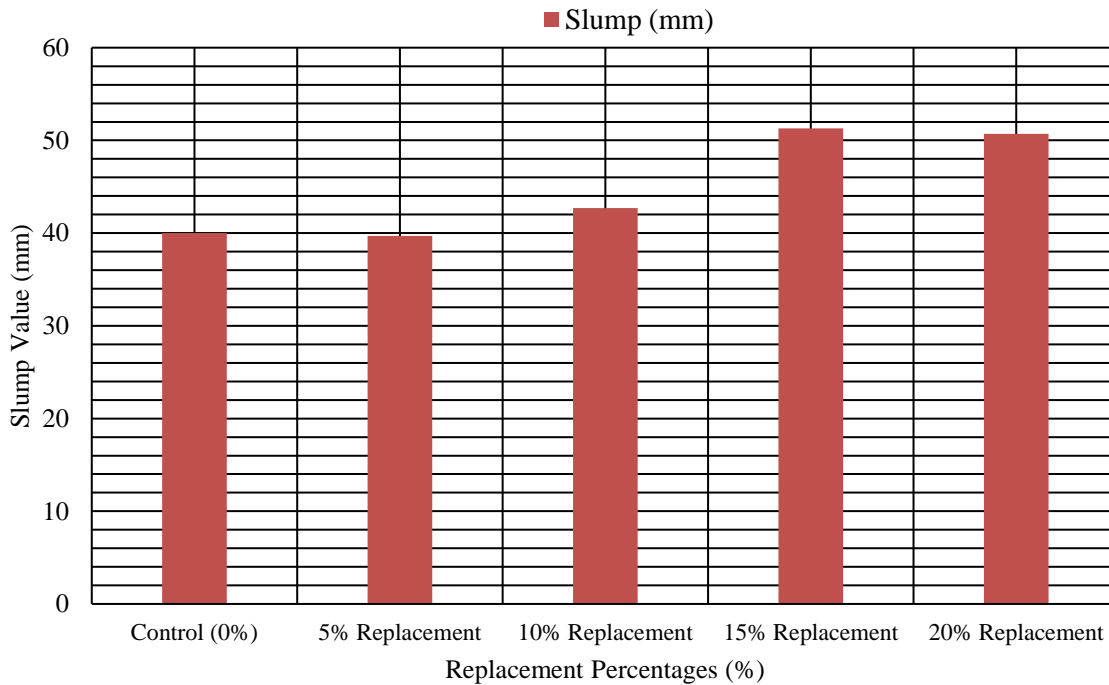


Figure 4.3: Result of slump value at varying % replacement

Slump cone with height of 30cm was used for this experiment. This experiment helps in determining the workability of the concrete mix. Concrete can be classified as low, medium

or high slump depending on the value obtained from the slump test. Low slump has a range between 0 to 5cm, medium slump has a range between 5 to 10cm while high slump has a range between 10 to 15cm. Anything above 15cm indicates a high mix and may indicate mix problems depending on the purpose of the mix. From the results shown in the figure below, 0% replacement of cement with BPA and coarse aggregate produced an extremely high slump while 5 to 15% replacements produced high slumps. From the rate of decrease, this indicates that increasing the BPA content decreases the workability of the mix.

4.1.2.3 Compressive strength test

This test is of paramount importance as it provides a measure of the concrete's ability to withstand compressive loads. The test confirms whether the concrete meets the target strength specified in the structural design. This experiment was conducted using compressive testing machine and the results are as shown below in Table 4.5-4.7. The compressive strength result is the most important parameter for any concrete mix as it shows the strength of the mix. Due to time constraint, the strength could only be determined after 7, 14 and 28 days but nevertheless, concrete is expected to have attained between 50 to 65 % of its final strength after 7 days of curing. For our concrete grade M20, the strength after 28 days is expected to be will generally be lower than that of a control concrete with no ash added, with exact strength depending on the percentage of ash used. Studies show that small amounts (5%-10%) may slightly increase strength, but higher replacements (from 15%) will significantly decrease it as showed in Fig 4.4-4.6.

Table 4. 5: Compressive strength for concrete cubes at 7 days

Percentage (%)	Weight(kg)	Compressive Force(KN)	Compressive Strength(N/mm ²)	Average Strength(N/mm ²)
0	8.570	271.418	12.063	12.52
	8.585	307.598	13.671	
	8.590	266.018	11.823	
5	8.575	272.925	12.130	11.6
	8.570	240.705	10.698	
	8.590	269.438	11.975	
10	8.585	306.900	13.640	13.35
	8.575	292.275	12.990	
	8.580	301.995	13.422	
15	8.595	292.995	13.022	12.73
	8.590	292.590	13.004	
	8.595	273.623	12.161	
20	8.585	267.570	11.892	11.80
	8.585	260.685	11.586	
	8.575	266.378	11.839	

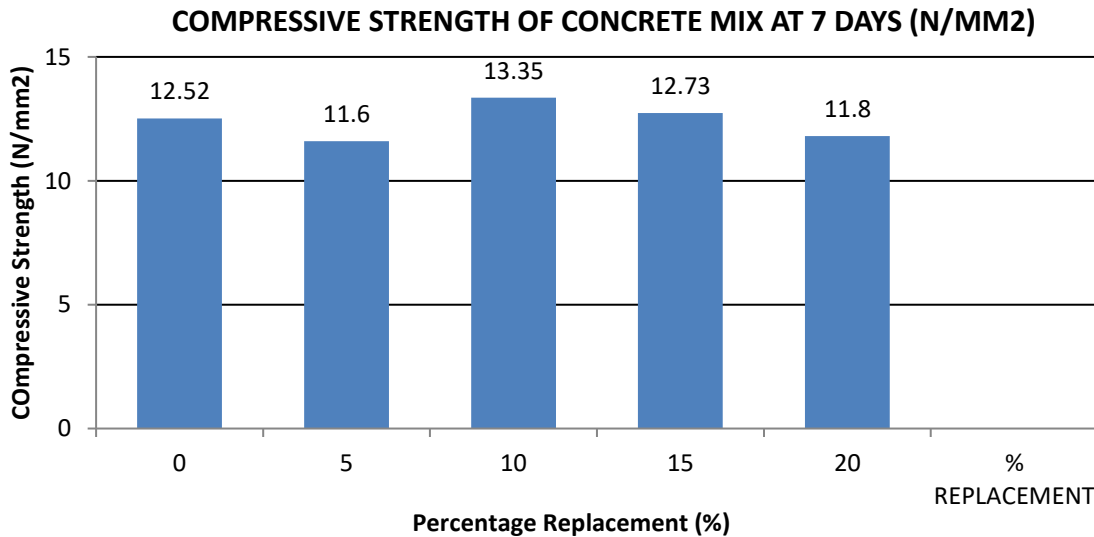


Figure 4.4: Chart showing comparison between the values of Average Compressive Strength for 7 days

Table 4.6: Compressive strength for concrete cubes at 14 days

Percentage (%)	Weight(kg)	Compressive Force(KN)	Compressive Strength(N/mm ²)	Average Strength(N/mm ²)
0	8.507	342.788	15.285	15.27
	8.513	342.405	15.218	
	8.508	344.363	15.305	
5	8.568	345.825	15.370	15.36
	8.574	345.870	15.372	
	8.562	345.173	15.341	
10	8.516	368.573	16.381	16.34
	8.518	366.638	16.295	
	8.521	367.988	16.355	
15	8.543	351.765	15.634	15.62
	8.512	350.775	15.590	
	8.551	351.720	15.632	
20	8.502	308.093	13.693	13.71
	8.511	316.665	14.074	
	8.509	300.600	13.360	

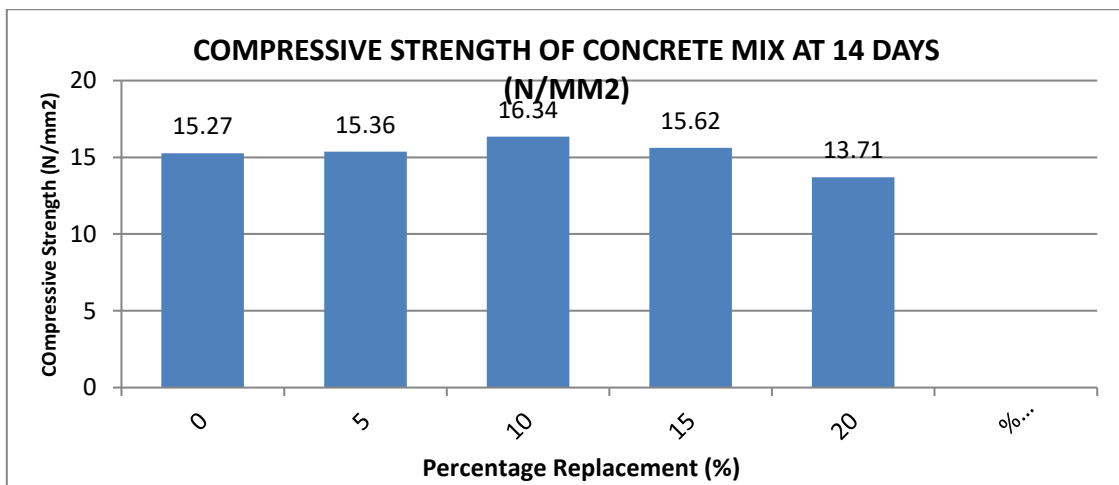


Figure 4.5: Chart showing comparison between the values of Average Compressive Strength for 14 days

Table 4.7 : Compressive strength for concrete cubes at 28 days

Percentage (%)	Weight(kg)	Compressive Force(KN)	Compressive Strength(N/mm ²)	Average Strength(N/mm ²)
0	8.521	437.310	19.436	19.34
	8.517	425.880	18.928	
	8.562	442.305	19.658	
5	8.567	427.613	19.005	19.27
	8.552	422.933	18.797	
	8.515	450.428	20.019	
10	8.558	448.943	19.953	20.04
	8.577	451.463	20.065	
	8.522	452.138	20.095	
15	8.522	419.063	18.625	18.36
	8.531	404.753	17.989	
	8.524	415.418	18.463	
20	8.526	381.218	16.943	17.10
	8.513	385.245	17.122	
	8.529	391.860	17.146	

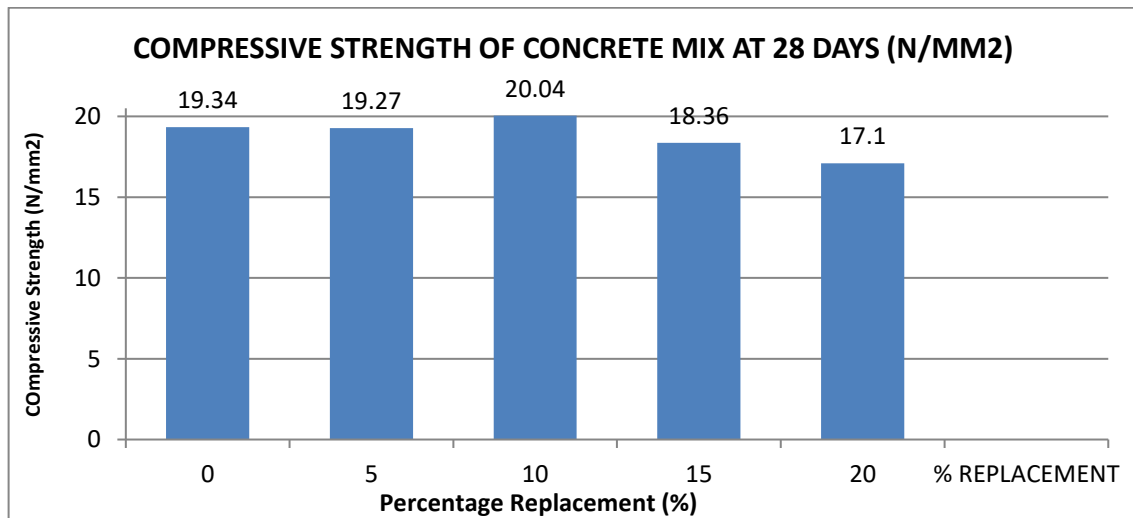


Figure 4.6: Chart showing comparison between the values of Average Compressive Strength for 7 days

4.1.2.4 Flexural strength test

This test is also known as the modulus of rupture test which is used to determine the flexural strength of concrete beams and it is crucial in evaluating the ability of concrete to withstand bending forces. This experiment was conducted using flexural testing machine and the results are as shown below. The results in Table 4.8 indicate a general decline in flexural strength as the percentage of PBPA replacement increases. The control mix (0% replacement) exhibited the highest average flexural strength of 3.63 N/mm² suggesting that conventional concrete has a strong early-age flexural capacity, with the he 5% and 10% PBPA mixes exhibited slight reductions in strength (3.43 N/mm² and 3.40 N/mm², respectively) suggesting that a lower percentage of PBPA does not significantly compromise early-age flexural properties. While the 20% replacement mix recorded the lowest strength at 2.93 N/mm² indicating that higher PBPA content adversely affects the concrete's ability to resist bending forces as illustrated in Fig 4.7.

The results in Table 4.9 at 28 days, showed that the control mix exhibited the highest flexural strength of 4.37 N/mm², demonstrating that ordinary Portland cement (OPC) maintains superior long-term flexural strength, with 5% and 10% Replacement: The flexural strength of these mixes was 4.10 N/mm² and 4.03 N/mm², respectively suggesting that up to 10% PBPA replacement still maintains satisfactory flexural properties, though slightly lower than the control, while the strength dropped to 3.83 N/mm² and 3.63 N/mm² for the 15% and 20% replacement, confirming that PBPA beyond 10% replacement significantly reduces the beam's ability to withstand flexural loads as illustrated in Fig 4.9. The results suggest that PBPA can be used as a partial replacement for cement in concrete up to 10% without significantly compromising flexural strength. However, higher replacement levels lead to a noticeable

decline in strength, making them unsuitable for load-bearing structural applications requiring high flexural resistance.

Table 4.8 : Flexural strength for concrete beams at 7 days

% Replacement	Flexural strength	Average strength
0	3.50 3.80 3.60	3.63
5	3.30 3.60 3.40	3.43
10	3.20 3.50 3.50	3.40
15	3.00 3.30 3.10	3.13
20	2.80 3.10 2.90	2.93

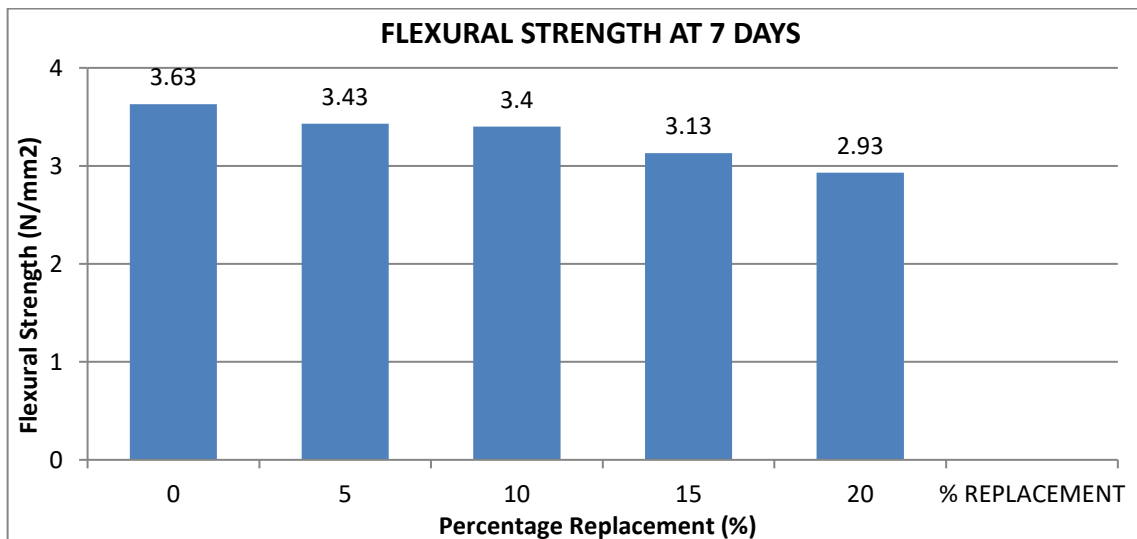


Figure 4.7: Chart showing comparison between the values of Average Flexural Strength for 7 days

Table 4.9 : Flexural strength for concrete beams at 28 days

% Replacement	Flexural strength	Average strength
0	4.20 4.60 4.30	4.37
5	4.00 4.20 4.10	4.10
10	3.90 4.20 4.00	4.03
15	3.70 4.00 3.80	3.83
20	3.50 3.80 3.60	3.63

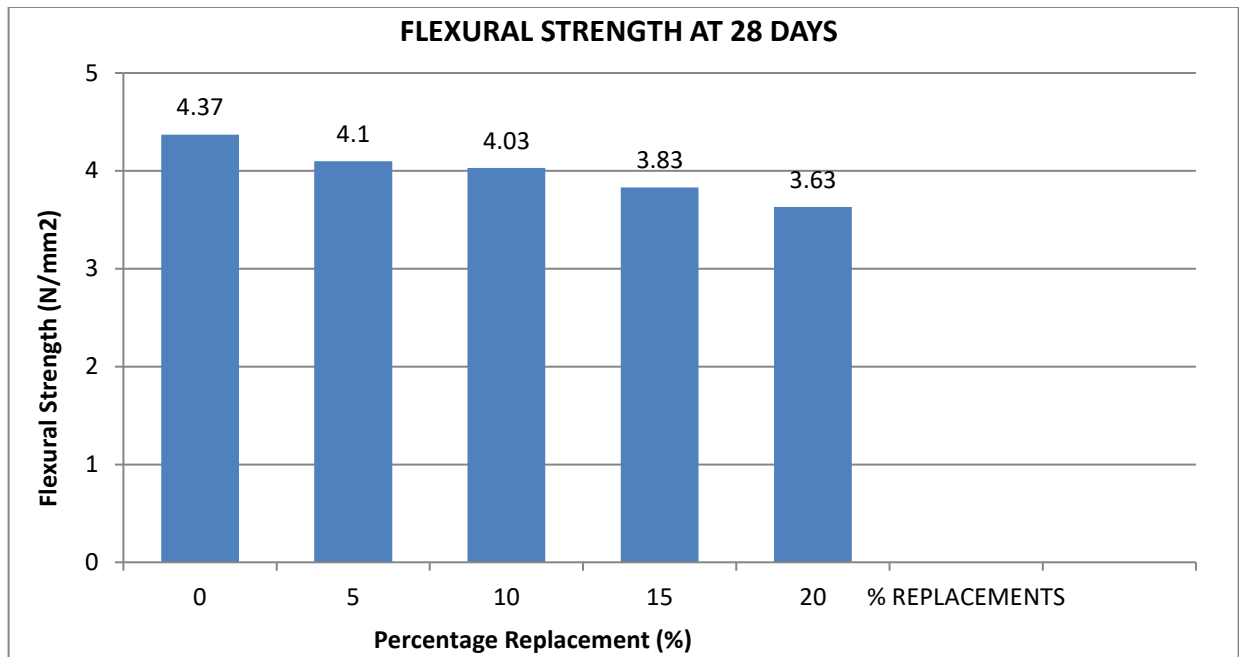


Figure 4.8: Chart showing comparison between the values of Average Flexural Strength for 28 days

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

In conclusion, this study aimed to explore the mechanical properties of concrete when pulverized glass is used as a partial substitute for fine aggregates. The investigation focused on evaluating the suitability, performance, and environmental benefits of using pulverized glass as an alternative material in concrete production.

Based on the experimental results and analyses conducted in this study, the following conclusions can be drawn:

1. The specific gravity of banana peel ash (BPA) was found to be 2.69, which is lower than the typical range for good-quality cement (3.12 - 3.15). This suggests that BPA is a finer material and may impact water demand, setting time, and overall concrete performance.
2. The results of sieve analysis for coarse aggregate confirmed that the majority of particles were retained on the 5.7mm sieve and above, indicating that the aggregates used were relatively small but within acceptable limits for structural concrete applications.
3. The slump test results indicated that increasing BPA replacement led to a reduction in workability. While the 0% replacement mix exhibited an extremely high slump, replacements between 5% and 15% resulted in high slumps, with a gradual decrease as the BPA content increased. This suggests that BPA reduces the fluidity of the mix, likely due to its finer particle size and higher surface area.
4. The compressive strength of concrete decreased as the percentage replacement of cement with PBPA increased. At 7 days, 10% replacement exhibited the highest strength, indicating an early strength gain advantage. At 14 days, the 10% replacement mix still

showed the highest strength, but the 15% and 20% mixes had noticeably lower values. At 28 days, the control (0% replacement) mix exhibited the highest strength (19.34 N/mm²), while the 10% replacement mix (20.04 N/mm²) showed a slight improvement, suggesting an optimal replacement level. However, beyond 10%, compressive strength declined significantly.

5. The flexural strength of concrete beams also decreased with increasing PBPA content. The 10% replacement mix maintained a relatively close value to the control mix, but beyond 15%, a significant reduction in flexural strength was observed.

Overall, the results indicate that PBPA can be used as a partial replacement for cement in concrete, particularly at a 10% replacement level, where strength properties were comparable to or slightly better than the control mix. However, higher replacement levels (15% and above) lead to a significant reduction in both compressive and flexural strength.

5.2 RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

1. A replacement level of up to 10% PBPA is recommended for structural applications, as it provides comparable or slightly enhanced strength while maintaining acceptable workability.
2. Higher replacement levels (15% and beyond) should be avoided for load-bearing structures due to reduced strength.
3. Since PBPA reduces workability, adjustments such as incorporating plasticizers or increasing the water-to-cement ratio should be considered to enhance fluidity without compromising strength.

4. Future studies should focus on the long-term durability of PBPA-modified concrete, including resistance to sulphate attack, carbonation, and permeability.
5. The effect of different curing conditions (e.g., steam curing, air curing) on the performance of PBPA concrete should also be investigated.
6. The use of PBPA in concrete presents a sustainable and eco-friendly alternative by reducing cement consumption and utilizing agricultural waste.

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APPENDIX





