

**EXPERIMENTAL STUDY ON PARTIAL REPLACEMENT OF CEMENT WITH
EGGSHELL POWDER IN CONCRETE DEVELOPMENT.**

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PLAGIARISM

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DEDICATION

I dedicate this project to the Almighty God for His unending grace, wisdom, and strength throughout my academic pursuit. Special dedication goes to my wonderful parents, Mr. and Mrs. Inofe, whose love, sacrifices, and unwavering support have been a constant source of motivation. I also extend this dedication to my siblings, friends, and mentors for their encouragement and steadfast belief in me.

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ABSTRACT

This study investigated the effect of partially replacing Ordinary Portland Cement (OPC) with eggshell powder (ESP) in concrete production as a sustainable approach to reduce cement consumption and utilize agricultural waste. The aim of the study was to evaluate the performance of concrete containing eggshell powder as a partial replacement for cement. The specific objectives were to determine the workability of concrete containing varying proportions of ESP, evaluate its compressive strength, assess its water absorption capacity as an indicator of durability, and identify the optimal ESP replacement level that yields the best concrete performance.

The experimental study was conducted by preparing concrete mixes with 0%, 5%, 10%, 15%, and 20% replacement of cement with eggshell powder. Waste eggshells were collected, cleaned, dried, ground into fine powder, and sieved before use. Concrete cubes were cast and cured in water, after which several laboratory tests were performed. Workability of the fresh concrete was determined using the slump test, compressive strength was measured at 7, 14, and 28 days using a compression testing machine, and water absorption tests were carried out at 28 days to evaluate the durability-related properties of the hardened concrete.

The results showed that workability slightly increased at 5% ESP replacement, indicating improved particle packing within the mix, but gradually decreased at higher replacement levels due to increased water demand of the fine ESP particles. The compressive strength of the concrete improved at moderate replacement levels, with the optimum strength obtained at 15% ESP replacement after 28 days of curing, while further increase in ESP content led to a reduction in strength. The water absorption values for all concrete mixes were below 10%, indicating that the inclusion of ESP did not adversely affect the durability of the concrete. Based on the findings, the study concluded that eggshell powder can effectively replace cement up to 15% without significantly compromising the essential properties of concrete. It is therefore recommended that ESP be considered as a sustainable partial cement replacement material in concrete production, particularly for applications such as pavements, floor screeds, and foundations, where environmentally friendly and cost-effective construction materials are desirable.

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ACRONYMS

ACI	- American Concrete Institute
ASTM	- American Society for Testing and Materials
BS	- British Standards Institution
BS EN	- British Standard European Norm
CaCO ₃	- Calcium Carbonate
CO ₂	- Carbon Dioxide
CTM	- Compression Testing Machine
DOE	- Department of Environment
ESP	- Eggshell Powder
FAO	- Food and Agriculture Organization of the United Nations
GPS	- Global Positioning System
IEA	- International Energy Agency
LGA	- Local Government Area
MPa	- Megapascal (unit of pressure/strength)
N	- Newton (unit of force)
OPC	- Ordinary Portland Cement
SCM	- Supplementary Cementitious Material
SCMs	- Supplementary Cementitious Materials

- SEM - Scanning Electron Microscopy
- TGA - Thermogravimetric Analysis
- UNEP - United Nations Environment Programme
- WBCSD - World Business Council for Sustainable Development
- XRD - X-Ray Diffraction

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Concrete remains the most widely used construction material worldwide, valued for its strength, durability, and versatility. However, its essential ingredient cement has a major environmental downside. Cement production alone is responsible for approximately 8% of global carbon dioxide (CO₂) emissions, primarily due to the calcination of limestone and the combustion of fossil fuels (International Energy Agency, 2020). On a broader scale, the construction sector accounts for nearly 37% of global greenhouse gas emissions, making it a significant driver of climate change (United Nations Environment Programme, 2020). These alarming figures underscore the urgent need for more environmentally responsible alternatives in construction practices, particularly in the formulation of concrete.

To address these challenges, the industry has increasingly turned to sustainable construction approaches, including the use of waste-derived materials to partially replace conventional cement. One such material under investigation is eggshell powder (ESP) a waste by-product from food industries and households. Eggshells are rich in calcium carbonate (CaCO₃), a compound chemically similar to limestone, which is the primary raw material used in cement manufacture (Oladele and Adebayo, 2017). This chemical similarity offers a compelling rationale for considering eggshells as a partial replacement for cement in concrete production.

The environmental benefits of utilizing ESP are twofold. First, it diverts organic waste from landfills, mitigating the public health and environmental hazards posed by eggshell

accumulation. Second, it helps reduce dependence on cement, thereby lowering emissions associated with its production. Research has shown that when properly processed, ESP can be blended with cement to produce concrete of acceptable performance, supporting both waste management and low-carbon construction objectives (Olofinnade, Ede and Ndambuki, 2020).

Despite these promising findings, further investigation is needed to understand the effect of eggshell powder on concrete characteristics under varying mix ratios and to identify the most effective ways to incorporate it into practical construction applications. This study therefore aims to explore the potential of ESP as a partial cement replacement in concrete, contributing to the advancement of sustainable material use in the construction industry and promoting eco-friendly alternatives to traditional cement.

1.2 Statement of the Problem

The construction industry heavily depends on concrete, with cement serving as the primary binding agent. However, due to the environmental concerns associated with cement production, there is increasing interest in identifying alternative materials that can partially replace cement in concrete. One such material is eggshell powder (ESP), which is derived from processed eggshell waste and offers potential benefits as a sustainable additive in concrete.

Although several studies have investigated the incorporation of ESP into concrete, findings have varied across different replacement levels, materials, and testing conditions. As a result, further research is necessary to better understand how ESP affects concrete performance and how best to apply it under specific mix designs and environmental conditions.

This study aims to contribute to that body of knowledge by evaluating the effects of varying ESP replacement levels on selected concrete properties. The research focuses on determining the most suitable proportion of eggshell powder that yields favorable results, thereby offering practical guidance on its application.

By providing evidence-based insights, the study intends to assist researchers, material engineers, and construction professionals in exploring sustainable alternatives in cement-based construction.

1.3 Aim and Objectives

The main aim of this research is to evaluate the effect of partially replacing cement with eggshell powder on the overall performance and quality of concrete with specific objectives in order to:

- i. To identify the optimal replacement eggshell powder replacement that yields the best concrete performance.
- ii. To evaluate the compressive strength of concrete with eggshell powder as a partial cement replacement.
- iii. To assess the water absorption capacity of the concrete as an indicator of porosity and potential durability.
- iv. To determine the workability of concrete containing varying proportions of eggshell powder.

1.4 Scope of Study

This research focuses on experimentally studying how replacing part of ordinary Portland cement with eggshell powder (ESP) affects concrete. The study examines how different

percentages of ESP influence certain properties of concrete, based only on laboratory tests carried out under controlled conditions. All tests will be conducted in the Structural Laboratory of the Department of Civil Engineering, University of Benin. The experimental activities to be carried out include:

- i. Collecting and grinding waste eggshells into fine powder
- ii. Preparing concrete mixes with selected ESP replacement levels
- iii. Testing the workability of fresh concrete using the slump cone method
- iv. Casting concrete cube samples
- v. Curing the concrete in water
- vi. Testing the compressive strength of the hardened concrete
- vii. Determining the water absorption capacity of the concrete

This study is limited to short-term laboratory tests and does not cover long-term durability aspects like resistance to chemicals, sulfate attack, or temperature changes. It also does not include microstructural testing such as SEM or XRD, nor does it consider environmental impact, cost analysis, or full-scale construction applications. All findings are based on laboratory conditions only.

1.5 Justification of Study

The production of cement contributes significantly to global carbon dioxide emissions, accounting for nearly 8% of the total CO₂ released into the atmosphere (Andrew, 2018).

With concrete being the most widely used construction material, there is a growing need to reduce the environmental burden associated with cement by incorporating alternative

materials. One such alternative is eggshell powder, a waste by-product primarily composed of calcium carbonate, which has chemical similarities to limestone—the principal raw material in cement production (Olawaju et al., 2021).

Eggshells are abundantly available in the environment as food waste, yet their improper disposal poses environmental and health hazards (Akinyele and Akinyele, 2015). By converting this waste into a construction material, the study addresses two challenges simultaneously: reducing waste and decreasing cement dependency. Research has shown that the partial replacement of cement with ESP can maintain or enhance key properties of concrete such as compressive strength and durability, particularly when used in moderate proportions (Adesanya and Raheem, 2010; Amu et al., 2005).

This study is therefore justified by its potential to promote sustainable waste management, reduce cement consumption, and explore the technical feasibility of using eggshell powder in concrete applications. It contributes to the broader effort toward environmentally responsible construction practices while also supporting innovation in the use of locally available waste materials.

CHAPTER TWO

LITERATURE REVIEW

This chapter presents a comprehensive review of existing literature relevant to the use of eggshell powder (ESP) as a partial replacement for cement in concrete. The review begins with an overview of the key materials involved in concrete production, including cement and aggregates, and discusses their properties and environmental impacts. It then explores the use of agricultural waste materials in concrete, with a particular focus on eggshells their sources, composition, and processing methods. Following this, the effects of ESP on concrete properties such as workability, compressive strength, and water absorption are examined. Finally, the chapter identifies gaps in the current research that justify the need for the present study.

2.1 Concrete Materials and their Properties

Concrete is a composite construction material composed primarily of cement, aggregates (fine and coarse), and water. Each of these components plays a vital role in determining the overall performance and durability of the concrete. Understanding the properties of these materials is essential to evaluating the effects of alternative cement replacements such as eggshell powder.

2.1.1 Cement

Cement serves as the primary binding agent in concrete, responsible for initiating the chemical process of hydration, which leads to the hardening and strength development of the material. The most commonly used type in construction is Ordinary Portland Cement (OPC), which is composed mainly of calcium silicates, aluminates, and ferrites.

The chemical and physical properties of cement significantly influence concrete quality. Chemically, cement consists largely of calcium oxide, silica, alumina, and iron oxide, which react with water to form hydrated compounds. Physically, cement fineness affects the rate of hydration and strength gain. Proper cement quality ensures adequate strength, durability, and workability in concrete.

However, cement production is energy-intensive and a major source of carbon dioxide (CO₂) emissions globally. The calcination of limestone and fossil fuel combustion during cement manufacturing contribute to approximately 8% of global CO₂ emissions. Consequently, reducing cement usage by partially replacing it with alternative materials has become an important focus in sustainable construction (Neville, 2012; International Energy Agency, 2020).

2.1.2 Aggregates

Aggregates, which include fine aggregates (such as sand) and coarse aggregates (such as granite or crushed stone), constitute the bulk of concrete volume and provide mechanical strength and dimensional stability. Fine aggregates fill voids between coarse particles, contributing to the density and workability of the mix.

The physical properties of aggregates such as particle size distribution, shape, texture, grading, and moisture content have a direct impact on the workability, strength, and durability of concrete. Well-graded, clean, and durable aggregates lead to better concrete performance, while poor-quality aggregates can cause segregation, reduced strength, and durability issues (Mindess, Young and Darwin, 2003; American Concrete Institute, 2011).

2.1.3 Water and Admixtures

Water is essential in concrete for the hydration of cement and achieving workable consistency. The water-cement ratio is a key factor influencing the strength and durability of concrete; excess water can weaken the concrete, while insufficient water can prevent proper hydration.

Admixtures are chemical additives that modify concrete properties, such as accelerating or retarding setting time, improving workability, or enhancing durability. Though admixtures are important, this study focuses primarily on the use of ESP as a cement replacement and does not extensively explore admixtures.

2.2 Agricultural Waste Materials in Concrete

The construction industry has increasingly explored the use of agricultural waste materials as partial replacements for conventional cement in concrete, aiming to reduce environmental pollution, conserve natural resources, and manage waste sustainably. Agricultural waste materials are often rich in silica, alumina, or calcium-based compounds, making them viable supplementary cementitious materials or fillers in concrete mixes.

Commonly studied agricultural by-products include rice husk ash, sugarcane bagasse ash, palm kernel shells, corn cob ash, and eggshell powder. These materials are generally available in large quantities, especially in developing countries, and pose a disposal challenge when left unmanaged. Utilizing them in construction helps address the dual challenges of environmental sustainability and waste reduction (Olawaju et al., 2021).

The performance of agricultural waste in concrete depends on its chemical composition, fineness, and compatibility with other mix constituents. Many of these materials exhibit pozzolanic properties meaning they can react with calcium hydroxide released during cement hydration to form additional cementitious compounds that improve strength and durability. Others serve primarily as filler materials, enhancing the microstructure of concrete by reducing voids and improving particle packing (Raheem et al., 2012).

Studies have shown that incorporating agricultural waste in concrete can lead to improvements in workability, strength development, thermal performance, and resistance to environmental attacks, particularly when used in optimal proportions. However, excessive replacement levels may reduce strength or alter setting times due to changes in chemical reactivity or particle morphology (Amran et al., 2021).

Although pozzolanic materials like fly ash and silica fume are well-established in practice, agricultural alternatives are increasingly attracting research interest due to their cost-effectiveness and local availability. Among these, eggshell powder (ESP) has emerged as a promising material due to its high calcium carbonate content, which is chemically similar to the limestone used in cement production (Akinyele and Akinyele, 2015). This has motivated several researchers to evaluate its potential use as a partial cement substitute in concrete applications.

2.3 Eggshell as a Construction Material

Eggshells are a widely available waste material rich in calcium carbonate, which is chemically similar to the limestone used in cement production. This makes eggshell powder a potential

sustainable alternative for partial cement replacement in concrete, helping to reduce environmental waste while improving certain concrete properties.

2.3.1 Sources and Availability of Eggshell Waste

Eggshells are a by-product of the poultry and food processing industries, generated in large quantities worldwide through domestic, commercial, and industrial consumption of eggs. Globally, over 70 million metric tons of eggs are produced annually, resulting in a substantial quantity of eggshell waste (FAO, 2021). In regions like Nigeria, where poultry farming is common, eggshell waste is abundantly available and typically discarded as solid waste without structured management.

Improper disposal of eggshells in landfills and open environments can lead to environmental and health issues, such as unpleasant odors, pest attraction, and slow biodegradation. Consequently, their reuse in construction not only addresses waste disposal problems but also contributes to sustainable building practices (Akinyele and Akinyele, 2015). The growing need for eco-friendly materials has encouraged researchers to explore eggshells as an alternative material in cement-based composites.

Eggshells are primarily composed of calcium carbonate (CaCO_3), the same main component found in limestone, which is the principal raw material in cement production. This chemical similarity makes them a viable substitute for a portion of cement in concrete. Additionally, eggshells can be sourced locally at minimal cost, making them a sustainable and economical material in construction, particularly in developing regions (Adesanya and Raheem, 2010).

2.3.2 Chemical Properties of Eggshell Powder

The chemical composition of eggshells is largely dominated by calcium carbonate (CaCO_3), typically accounting for 94–97% of the material. Minor components include magnesium carbonate, calcium phosphate, and trace amounts of organic matter (Amu, Fajobi and Oke, 2005). This high calcium content is responsible for the cementitious or filler behavior observed when eggshell powder is used in concrete.

The chemical similarity between CaCO_3 in eggshells and the limestone used in cement manufacturing explains its potential as a partial cement replacement. Although eggshell powder does not possess strong pozzolanic activity on its own, it can contribute to the early strength gain of concrete through micro-filler effects and, to a lesser extent, through weak pozzolanic reactions under certain conditions (Raheem, Adesanya and Adeyemi, 2012).

2.3.3 Physical Properties of Eggshell Powder

Physically, eggshell powder is off-white in color and becomes fine and uniform when properly processed. Its fineness, particle size distribution, and specific surface area are key characteristics that influence its performance in concrete. Finer particles enhance packing density, reduce porosity, and promote better bonding within the cement matrix (Oyenuga, Raheem and Olaniyi, 2020).

The processing method of eggshell powder directly affects its physical quality. Standard preparation includes washing, drying at 100–120°C, grinding, and sieving to achieve cement-like fineness. Poorly processed ESP can result in non-uniformity and reduced strength, while

properly prepared ESP can fill voids between cement particles and improve the microstructure of the concrete (Olawajaju et al., 2021).

However, it is important to note that excessive addition of ESP may reduce workability or cause segregation, especially if particle sizes are inconsistent or if replacement levels exceed the optimal range (Adesanya and Raheem, 2010).

2.4 Effects of Eggshell Powder on Concrete Properties

The incorporation of eggshell powder into concrete has attracted increasing interest due to its potential to enhance performance while reducing cement usage and environmental impact. Several studies have investigated the effects of ESP on key concrete properties such as workability, compressive strength, and water absorption. The performance of concrete with ESP largely depends on the percentage replacement, particle fineness, and mix design parameters.

2.4.1 Workability

Workability refers to the ease with which concrete can be mixed, placed, compacted, and finished. The addition of ESP to concrete tends to influence workability depending on the replacement level and particle size. Studies indicate that low to moderate ESP replacement (typically between 5% and 10%) has minimal or slightly improving effects on workability due to its fine texture, which enhances paste cohesion (Adesanya and Raheem, 2010). However, higher replacement levels can lead to reduced workability because of the increased surface area and water demand associated with fine ESP particles (Raheem, Adesanya and Adeyemi, 2012).

To counteract this, adjustments to the water-cement ratio or the use of superplasticizers may be required. The shape and fineness of ESP particles also affect flowability, and excessive use may lead to segregation or stiff mixes.

2.4.2 Compressive Strength

Compressive strength is one of the most important mechanical properties of concrete. Numerous studies have shown that partial replacement of cement with ESP up to an optimal level can maintain or even improve the compressive strength of concrete. This is attributed to ESP's ability to act as a micro-filler, reducing voids and densifying the concrete matrix (Amu, Fajobi and Oke, 2005; Oyenuga, Raheem and Olaniyi, 2020).

Adesanya and Raheem (2010) reported that compressive strength increased slightly at 5–10% ESP replacement levels but declined at higher levels due to dilution of the cementitious content. The decline beyond optimal dosage is often due to ESP's relatively low pozzolanic reactivity and inability to fully replace cement's binding effect at high concentrations.

2.4.3 Water Absorption

Water absorption is a measure of the concrete's porosity and is closely linked to its durability. Lower absorption rates indicate a denser and less permeable structure, which improves resistance to water ingress, freeze-thaw cycles, and chemical attacks. The inclusion of finely ground ESP in appropriate quantities has been found to reduce water absorption due to its filling effect on the cement matrix (Raheem et al., 2012).

At optimal replacement levels (usually around 5–10%), ESP contributes to a less porous concrete structure. However, excessive addition may introduce unreacted particles and create micro-pores, which can increase water uptake and negatively affect long-term durability (Olarewaju et al., 2021).

2.5 Processing of Eggshell Powder

The quality and performance of eggshell powder in concrete are significantly influenced by its method of preparation. Studies shows that proper processing is essential to ensure the removal of impurities, enhance particle fineness, and promote uniformity, which all contribute to the consistency and effectiveness of ESP in cementitious applications.

The typical process begins with the collection of eggshell waste from households, markets, or poultry farms. The shells are then thoroughly washed with water to remove membrane residues and organic matter. After washing, they are sun-dried or oven-dried at temperatures ranging from 100°C to 120°C for about 12 to 24 hours to eliminate moisture and pathogens (Oyenuga, Raheem and Olaniyi, 2020).

Once dried, the shells are crushed and ground using a mechanical grinder until a fine powder is obtained. The final step involves sieving the powder, usually through a 75-micron sieve, to obtain a particle size distribution comparable to that of Portland cement (Olarewaju et al., 2021). The finer the powder, the better its ability to act as a micro-filler or react with calcium hydroxide in the cement matrix.

Well-processed ESP enhances the workability, compressive strength, and overall durability of concrete by ensuring better packing density and uniform dispersion within the cementitious system.

2.6 Challenges and Solutions in Using Eggshell Powder

While the use of eggshell powder (ESP) in concrete presents several environmental and structural benefits, its practical application is not without challenges. These limitations, if unaddressed, could affect the reliability, scalability, and performance of ESP in cement-based construction. This section discusses key challenges associated with ESP use and outlines suggested mitigation strategies based on existing literature.

2.6.1 Variability in Eggshell Quality

Eggshell quality varies due to differences in bird species, feed composition, laying conditions, and handling practices. These variations can affect calcium carbonate content, shell thickness, and other properties, resulting in inconsistent ESP performance across concrete batches (Oyenuga, Raheem and Olaniyi, 2020).

Solution:

To address this, researchers recommend the standardization of collection and processing methods, such as washing, controlled drying (typically at 100–120°C), and grinding to a consistent fineness. Implementing quality control protocols during ESP preparation can reduce variability and ensure more predictable behavior in concrete mixes (Olarewaju et al., 2021).

2.6.2 Processing Costs and Scalability

Although eggshells are cheap and abundant, the process of converting them into fine powder involves multiple steps — cleaning, drying, crushing, and sieving — which can be labor-intensive and require equipment. At industrial scale, this raises cost and logistical concerns (Olawajaju et al., 2021).

Solution:

To reduce costs and improve feasibility, researchers suggest adopting low-energy drying methods, such as solar drying, and encouraging community-level or on-site processing in areas with high eggshell availability. These approaches can lower energy use and make ESP more accessible for small to medium-scale construction projects (Oyenuga et al., 2020).

2.6.3 Performance Issues at High Replacement Levels

While ESP can improve or maintain performance at low replacement levels (5–10%), using excessive quantities (15% or more) may weaken the mix. This is because ESP lacks sufficient pozzolanic activity to fully substitute cement and may cause reduced strength, increased porosity, and poor workability (Raheem, Adesanya and Adeyemi, 2012).

Solution:

Several studies recommend restricting ESP usage to optimal replacement levels (not exceeding 10%), beyond which performance tends to decline. In addition, combining ESP with other supplementary cementitious materials (SCMs), such as fly ash or silica fume, has been explored as a strategy to enhance performance at higher dosages (Adesanya and Raheem, 2010).

2.7 Research Gaps and Review of Related Works

The application of eggshell powder (ESP) as a partial replacement for cement in concrete has attracted increasing attention due to its potential for promoting sustainability. However, several critical aspects remain either underexplored or inconclusive in literature. This section outlines key research gaps, proposes future directions for study, and presents a comprehensive review of relevant studies in the field.

2.7.1 Research Gaps

Despite promising results, several important gaps still exist in the literature. Notably, some of these limitations were also not addressed in the present study:

- i. There is no standardized method for processing eggshell powder, which causes inconsistency in particle size, composition, and test results across different studies.
- ii. Durability properties such as sulfate resistance, shrinkage, and permeability have not been evaluated in this present study, limiting long-term performance insights.
- iii. Microstructural analyses such as SEM and XRD, which are essential to understanding the pozzolanic behavior of eggshell powder, were not included in this work.
- iv. There is no consensus in the literature regarding the optimal percentage of eggshell powder replacement, with recommended levels varying from 5% to 15%.
- v. Environmental and economic assessments such as life cycle analysis and cost–benefit evaluation have not been considered in this research, leaving questions about sustainability unanswered.

- vi. There is limited comparative research between eggshell powder and other agro-waste pozzolans like rice husk ash or palm kernel shell ash, making performance benchmarking difficult.
- vii. Field trials or real-life construction validations have not been conducted in this study, as the findings are based entirely on laboratory tests.
- viii. The effect of chemical admixtures on the workability and mechanical properties of ESP concrete was not explored in this study, despite known issues with consistency at higher replacement levels.

2.7.2 Review of Related Works

Several researchers have evaluated the use of eggshell powder as a partial cement replacement in concrete and mortar, with varying conclusions on performance, strength, and feasibility.

Adesanya and Raheem (2010) explored ESP as a cement replacement and found that a 10% substitution provided optimal compressive strength and workability. However, the performance declined at higher levels due to poor particle bonding.

Raheem, Adesanya and Adeyemi (2012) focused on long-term strength and durability, noting that ESP-blended concrete showed steady performance over extended curing periods, especially at 5%–10% replacement.

Amu, Fajobi and Oke (2005) applied ESP in soil stabilization and discovered that it significantly improved the load-bearing capacity of lateritic soils, indicating pozzolanic behavior even outside concrete applications.

Edwin and Bhattacharjee (2014) compared uncalcined and calcined ESP, concluding that calcination enhanced reactivity and bonding with cement hydrates, improving overall strength.

Olarewaju et al. (2021) provided a wide-ranging review of agro-waste pozzolans. They recognized ESP's high calcium carbonate content as beneficial but emphasized the need for microstructural analysis and process consistency for reliable results.

Bashir et al. (2023) examined the mechanical performance of cement mortar with ESP and reported improved compressive strength at 5% replacement. However, the strength deteriorated when ESP exceeded 15%, highlighting a dosage limit.

Oyenuga, Raheem and Olaniyi (2020) conducted a review on ESP processing and its application in cementitious materials. They pointed out that inconsistent particle size and drying techniques adversely affect pozzolanic activity and performance.

Olutoge, Oke and Adesanya (2012) evaluated ESP in concrete and observed reduced porosity and reasonable strength at 5%–10% replacement. They recommended further optimization of mix proportions and curing conditions.

Umar et al. (2022) investigated ESP as a cement substitute in eco-friendly concrete and noted that ESP can achieve comparable strength to control samples when properly processed. They also observed reduced CO₂ emissions and cost efficiency.

Akinyele and Akinyele (2015) emphasized the environmental risks associated with eggshell waste and advocated its conversion into useful construction material, aligning with the present study's sustainability motivation

CHAPTER THREE

METHODOLOGY

3.1 Materials and Equipment

This study employs the necessary materials and equipment to ensure accurate preparation and testing of concrete samples.

3.1.1 Materials List

- i. Ordinary Portland Cement
- ii. Fine Aggregate (Sand)
- iii. Coarse Aggregate (Granite)
- iv. Eggshell Powder (ESP)
- v. Water

3.1.2 Equipment List

- i. Mechanical Grinder
- ii. Sieve Set
- iii. Weighing Balance
- iv. Concrete Mixer
- v. Measuring Buckets
- vi. Trowel, tamping rod
- vii. Curing Tanks
- viii. Compression Testing Machine (CTM)
- ix. Slump Cone Set

- x. Cube Molds (150mm x 150mm x 150mm)
- xi. Drying Oven
- xii. Water Basin

3.2 Material Collection and Preparation

Ordinary Portland Cement (OPC): Ordinary Portland Cement will be used as the primary binder in all the concrete mixes. The cement will be purchased from a supplier in Benin City which will be stored in a dry, moisture free environment to prevent premature hydration.

Eggshell Powder (ESP): Eggshells will be collected from local sources such as restaurants, food vendors, and households. After collection, the eggshells will be thoroughly washed with clean water to remove organic impurities and the inner membrane. They will then be oven dried at 105°C for 24 hours to eliminate residual moisture (Oyenuga, Raheem and Olaniyi, 2020). The dried eggshell will be grinded using the mechanical grinder to produce a fine powder. The powdered material will be passed through a 75µm sieve to ensure uniform particle fineness that will be suitable for blending with cement. The processed eggshell powder will be stored in airtight containers to prevent contamination or moisture absorption.

Fine Aggregates: Natural river sand will be used as the fine aggregate, the sand will be collected from a local supplier in Benin City. It will be washed with clean water to remove silt, clay and organic impurities then air dried which will be stored in a clean, moisture free container to prevent contamination before use. The sand will be well graded and pass through a 4.75mm sieve to conform with the BS EN 12620 specifications.

Coarse Aggregate: Crushed granite stones of 20mm maximum size will serve as the coarse aggregate (Mindess, Young and Darwin, 2003). The aggregate will be surface dry and free of

harmful materials such as dust, clay or organic matter. Sieve analysis will be performed to confirm that the aggregate falls within the standard grading limits (ASTM C136 / C136M – 14, 2014). The test will involve drying the sample, passing it through a standard set of sieves (25mm, 20mm, 16mm, 12.5mm, 10mm, 4.75mm) and calculating the percentage retained on each sieve which will determine the particle size distribution.

Water: Clean, potable water will be used for both the concrete mixing and curing (Neville, 2012). It will be sourced from the Civil Engineering Laboratory, the water will be visually inspected to ensure it is clear, colorless and free from oil, debris or discoloration. It will be collected daily in clean covered containers and stored at room temperature which will be measured accurately using a measuring cylinder to maintain the water-cement ratio. The same source will also be used for the curing period to ensure uniformity (ACI Committee 308, 2001).

3.3 Mix Design and Proportioning

The concrete mix design for this research will follow the Department of Environment (DOE) method, aligned with BS EN 206 and ACI 211.1 guidelines. The design will aim for a 28-day target compressive strength of 25 MPa. Eggshell powder will be used to replace OPC at incremental levels of 0%, 5%, 10%, 15%, and 20% by weight (Montgomery, 2017).

A starting water-to-cement ratio of 0.5 will be adopted, subject to adjustment based on trial mix performance to achieve the desired workability (Neville, 2012). Aggregates will be proportioned by weight, and all other mix components will remain constant across batches, aside from the varying ESP content. The finalized mix proportions will be determined prior to specimen preparation for testing.

3.4 Experimental Procedure

The experimental procedure will consist of the following steps:

- i. Collection and cleaning of waste eggshells from local sources.
- ii. Drying and grinding eggshells into fine powder passing through a 75 μm sieve.
- iii. Procuring OPC, fine aggregate (river sand), coarse aggregate (12 mm crushed granite), and potable water.
- iv. Mixing concrete batches with eggshell powder replacing cement at 0%, 5%, 10%, 15%, and 20% by weight.
- v. Conducting slump cone tests to assess workability of fresh concrete. (BS EN 12350-2:2019).
- vi. Casting concrete into 100 mm cube molds in three layers with proper compaction.
- vii. Curing specimens in water at room temperature for 7, 14 and 28 days. (ACI Committee 308, 2001).
- viii. Testing compressive strength at 7, 14 and 28 days using a compression testing machine. (ASTM C39/C39M-21, 2021).
- ix. Performing water absorption tests on hardened concrete specimens. (BS 1881-122:2011).

3.5 Experimental Test Procedures

The experimental test procedures describe the tests and techniques used to assess the properties and performance of concrete mixes with eggshell powder

3.5.1 Slump Test (Workability)

Equipment: Slump cone, base plate, tamping rod, measuring scale and trowel

Procedure:

- i. Place the slump cone on a clean, non-absorbent base plate.
- ii. Fill the cone in three equal layers with freshly mixed concrete.
- iii. Tamp each layer 25 times with a steel tamping rod.
- iv. Level the top surface and lift the cone vertically without disturbance.
- v. Measure the vertical difference between the top of the cone and the slumped concrete.
- vi. Record the slump value (BS EN 12350-2:2019).

3.5.2 Compressive Strength Test

Equipment: 100mm cube molds, tamping rod, curing tank, compression testing machine (CTM)

Procedure:

- i. Cast concrete into cube molds in three layers, each compacted with 25 strokes.
- ii. Cover the molds and allow the concrete to set for 24 hours.
- iii. Demold the cubes and submerge them in a curing tank at $27 \pm 2^\circ\text{C}$.
- iv. At 7, 14 and 28 days, remove the cubes, surface dry them and place them in the CTM.
- v. Apply load gradually until failure occurs (ASTM C39/C39M-21, 2021)
- vi. Record the maximum load applied.
- vii. Calculate the compressive strength using $f_c = \frac{P}{A}$

Where: f_c = compressive strength (MPa)

P = maximum load (N)

A = cross-sectional area of the cube (mm^2)

3.5.3 Water Absorption Test

Equipment: Drying oven, weighing scale, water basin, concrete cube samples

Procedure:

- i. The concrete cubes will be removed and oven dry at 105°C for 24 hours after 28 days of curing.
- ii. Weigh and record the dry weight (W_1)
- iii. Immerse the cubes in clean water for 24 hours
- iv. Remove and surface dry it gently with a cloth
- v. Weigh and record the wet weigh (W_2)
- vi. Calculate the water absorption (BS 1881-122:2011).

3.6 Parameters Analyzed

- i. Compressive strength at 7, 14 and 28 days
- ii. Workability (slump test)
- iii. Water absorption

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

This chapter presents the results obtained from the laboratory investigation on the partial replacement of Ordinary Portland Cement (OPC) with eggshell powder (ESP) in concrete. The results are arranged according to the tests carried out, which includes the slump test for workability, compressive strength test at 7, 18 and 28 days and water absorption test at 28 days. The results are shown in tabular form and followed by analysis and discussion of findings in relation to existing literature.

4.2 Presentation of Results

The results of the slump test and compressive strength tests for concrete with varying percentages of eggshell powder are presented and compared with the control mix.

4.2.1 Slump Test Results

Table 4.1 Slump Test Values of Concrete at Different ESP Replacement Levels

Mix ID	ESP Replacement (%)	Slump (mm)
M0	0% (Control)	25
M1	5% ESP	30
M2	10% ESP	25
M3	15% ESP	20
M4	20% ESP	20

The slump values obtained were 25 mm (0% ESP), 30 mm (5% ESP), 25 mm (10% ESP), 20 mm (15% ESP) and 20 mm (20% ESP). The slight increase in workability at 5% ESP was followed by a reduction as the percentage of eggshell powder increased. This reduction is attributed to the fine particle size of ESP, which increases the surface area and therefore raises water demand. This behaviour agrees with Neville and Brooks (2010), who stated that the inclusion of finer supplementary materials in concrete generally reduces workability unless additional water or admixtures are provided. Overall, the concrete mixes fall within the low to medium workability range and are suitable for normal compaction.

4.2.2 Compressive Strength results

Table 4.2 Compressive Strength of Concrete (MPa) at 7-day Curing

ESP Replacement (%)	Cube 1 (MPa)	Cube 2 (MPa)	Cube 3 (MPa)	Average (MPa)
0%	17.96	17.65	16.34	17.32
5%	18.82	17.35	15.12	17.11
10%	17.66	15.51	15.31	16.16
15%	16.53	14.52	13.11	14.72
20%	13.63	12.38	11.89	12.63

4.2.3 7-Day Strength

The 7-day compressive strength result shows a general decrease in strength as the percentage of ESP increases. The control mix (0% ESP) recorded the highest strength of 17.32Mpa while the lowest strength value 12.63Mpa was obtained at 20% ESP replacement.

This observation is consistent with previous studies (Abbasi Dezfouli et al. 2020) which reported lower early-age strength in concrete mixes containing eggshell powder, especially at high replacement levels. At 7 days the pozzolanic reaction of ESP is still limited and the material behaves more like a filler rather than a strength contributing binder.

Table 4.3 Compressive Strength of Concrete at 14-day Curing

ESP Replacement (%)	Cube-1 (MPa)	Cube-2 (MPa)	Cube-3 (MPa)	Average (MPa)
0%	15.02	13.87	12.47	13.78
5%	17.81	16.89	13.64	16.11
10%	14.39	12.88	11.33	12.87
15%	16.14	15.77	15.66	15.86
20%	13.66	12.18	10.96	12.27

4.2.4 14-Day Strength

The compressive strength result at 14 days shows a similar trend to the 7-day result, with the strength values influenced by the ESP replacement percentage. The highest strength was recorded at 5% ESP replacement of 16.11Mpa, followed closely by 15% ESP replacement of 15.86Mpa. The control mix (0% ESP) produced 13.78 which is lower than both 5 and 15% mixes.

The result shows a slight recovery at 15% replacement which suggests the pozzolanic contribution of ESP becomes more pronounced between 7 and 14 days for some mix level. However, the strength reduced sharply at 10% and 20% ESP replacement which indicates the

higher replacement amount weakens the concrete due to reduced cement hydration products. This agrees with previous findings by Vaidya & Bastwadkar (2019), which reported that eggshell powder exhibits delayed pozzolanic reactivity and may not contribute significantly to early-age strength before 28 days.

Table 4.4 Compressive Strength of Concrete at 28-day Curing

ESP Replacement (%)	Cube-1 (MPa)	Cube-2 (MPa)	Cube-3 (MPa)	Average (MPa)
0%	17.58	17.21	16.83	17.2
5%	17.61	15.49	14.11	15.74
10%	16.22	15.45	14.91	15.53
15%	19.08	19.08	17.67	18.69
20%	13.36	13.21	12.51	13.03

4.2.5 28-Day Strength

The highest compressive strength at 28 days was obtained at 15% ESP replacement of 18.69Mpa, which is higher than the control (0% ESP) of 17.20Mpa. This indicates a moderate replacement level can enhance the strength of concrete. Similar findings were reported by Oliveira et al (2020) it was observed that ESP improves strength when used in optimum proportions due to its fine particle size and calcium carbonate content.

The strength reduction observed at 20% ESP replacement of 13.03 suggests that excessive substitution of cement reduces the amount of available clinker responsible for cement formation.

4.2.6 Water Absorption Test (28 Days)

The water absorption test was carried out on concrete cubes after 28 days of curing to assess the effect of eggshell powder on the durability of the concrete.

Table 4.5 Water Absorption Result at 28 Days

ESP Replacement (%)	Cube 1 Absorption (%)	Cube 2 Absorption (%)	Average (%)
0%	4.69	3.98	4.34
5%	4.24	3.52	3.88
10%	2.76	4.76	3.76
15%	4.04	4.29	4.17
20%	4.71	3.06	3.88

The water absorption values for all mixes ranged between 3.76% and 4.34%, which are within the acceptable threshold for durable concrete, typically less than 10%. The control mix (0% ESP) recorded the highest absorption value of 4.34%, while the lowest value (3.76%) occurred at 10% ESP replacement. Although the values do not show a consistent increasing or decreasing pattern, the results indicate that the inclusion of eggshell powder did not significantly affect water absorption. This implies that the durability of the concrete was not compromised by the partial replacement of cement.

4.3 Discussion of Findings

The results of the experimental investigation showed that the partial replacement of cement with eggshell powder (ESP) had varying effects on the fresh and hardened properties of

concrete. The slump test revealed that workability improved slightly at 5% ESP replacement but decreased at higher percentages, indicating higher water demand as ESP content increased. Despite the reduction in slump beyond 10% replacement, all mixes maintained low to medium workability, suitable for normal compaction.

The compressive strength results demonstrated that the optimum strength was achieved at 15% ESP replacement at 28 days, showing an improvement over the control mix. Strength decreased beyond this level, indicating that excessive ESP reduces the binding efficiency of the cement matrix. This suggests that ESP can contribute to strength development when used in moderate proportions.

Water absorption values for all mixes were below 10%, confirming acceptable durability levels. The lowest absorption occurred at 10% ESP replacement, suggesting a slightly denser microstructure at this level, although the difference across mixes was minimal. The inclusion of ESP did not negatively affect the resistance of concrete to moisture ingress.

Overall, the findings show that the incorporation of eggshell powder up to 15% can enhance compressive strength without compromising durability, although a slight reduction in workability is observed at higher replacement levels. Thus, ESP has potential as a sustainable partial cement replacement, especially in structural applications where strength and durability are key considerations.

4.4 Implications of Findings

The findings show that eggshell powder can be used as a partial replacement for cement up to 15% without significantly reducing the strength or durability of the concrete. This suggests

that ESP has potential as a low-cost, eco-friendly supplementary material, helping to reduce cement consumption and minimise environmental waste from discarded eggshells. The results support the possibility of incorporating agricultural waste into sustainable construction practices.

4.5 Chapter Summary

This chapter presented and analysed the results of the slump test, compressive strength test, and water absorption test for concrete containing varying percentages of eggshell powder. The findings were interpreted and compared with relevant literature, and the effects of ESP on workability, strength, and durability were discussed. The next chapter provides the conclusion, recommendations, and suggestions for further studies.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study examined the effect of partially replacing cement with eggshell powder (ESP) on the performance of concrete by evaluating its workability, compressive strength, water absorption characteristics, and determining the optimal replacement level.

The results obtained from the workability test indicated that the inclusion of eggshell powder slightly improved the workability of concrete at 5% replacement level. This improvement may be attributed to better particle packing and reduced voids within the concrete mix. However, as the percentage of eggshell powder increased beyond this level, a gradual reduction in workability was observed, which can be associated with the finer particles of eggshell powder increasing the water demand of the mix.

The compressive strength results revealed that concrete containing eggshell powder exhibited varying strength performance depending on the replacement level. The study showed that 15% replacement of cement with eggshell powder produced the optimum compressive strength, indicating that moderate substitution can contribute positively to the cementitious matrix. Beyond this level, the compressive strength began to decrease, suggesting that excessive replacement of cement may reduce the binding capacity required for strength development.

The water absorption test carried out to evaluate the durability-related properties of the concrete showed that all concrete mixes recorded water absorption values below 10%, indicating that the incorporation of eggshell powder did not adversely affect the durability of

the concrete. This suggests that concrete containing ESP maintains acceptable resistance to water penetration.

Based on the overall experimental findings, the study concludes that eggshell powder can be effectively used as a partial replacement for cement up to 15% without significantly compromising the key properties of concrete. The use of eggshell powder not only helps in reducing cement consumption but also promotes sustainable construction practices through the utilization of agricultural waste materials. Therefore, ESP presents a promising alternative material for environmentally friendly concrete production suitable for both structural and non-structural applications.

5.2 Recommendations

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

- i. Concrete mixes can safely incorporate up to 15% eggshell powder as a partial replacement for cement to achieve an optimal balance between workability, strength, and durability.
- ii. When higher percentages of ESP are used (above 10%), adjustments in water content or the use of suitable chemical admixtures are recommended to maintain adequate workability and ensuring proper compaction
- iii. The use of eggshell powder should be encouraged as a sustainable material in concrete production to reduce cement consumption and minimize environmental waste from discarded eggshells.

- iv. Builders and contractors can consider utilizing ESP concrete in applications such as pavements, floor screeds, foundations, and other moderate-strength structures where performance requirements are met.
- v. Construction stakeholders and policymakers should promote awareness of alternative cementitious materials, including ESP, as part of environmentally conscious construction practices. Integration of ESP in local concrete production can lower production costs, reduce carbon footprint, and provide a practical solution for managing eggshell waste.

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