EVALUATION OF LIGHTWEIGHT CONCRETE USING CRUSHED COCONUT SHELLS AS PARTIAL REPLACEMENT FOR COARSE AGGREGATE IN RIGID PAVEMENT CONSTRUCTION

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PLAGIARISM

This work, EVALUATION OF LIGHTWEIGHT CONCRETE USING CRUSHED COCONUT SHELLS AS PARTIAL REPLACEMENT FOR COARSE AGGREGATE IN RIGID PAVEMENT CONSTRUCTION, by AKWEMOH EDWIN FRANCIS, with Matriculation Number ENG1909143 of the Department of Civil Engineering, University of Benin City, Edo State. Nigeria has PASSED the PLAGIARISM TEST.

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DEDICATION

This project is humbly dedicated to Almighty God, who graciously sustained my life and bestowed upon me the wisdom and insight necessary to navigate each step of my academic path.

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ABSTRACT

This study evaluates lightweight concrete produced by partially replacing conventional coarse aggregate with crushed coconut shells, aiming to develop an eco-friendly and cost-effective solution for rigid pavement construction. The research investigates the feasibility of using coconut shells (a readily available agricultural waste) as a substitute to reduce concrete's overall weight while maintaining adequate structural performance.

A comprehensive experimental test was carried out in which concrete mixes were designed with varying levels of crushed coconut shell replacement (e.g., 0%, 10%, 20%, and 30%) for the coarse aggregate replacement. The fresh concrete properties were evaluated using standard slump tests, while the hardened concrete was tested for compressive, flexural, and splitting tensile strengths at 7, 14, and 28 days of curing. The tests were conducted following standard procedures, and the resulting data were tabulated and compared across different replacement percentages. The 7-day compressive strength for the control mix (0% replacement) was 21.09 N/mm², while the 10% replacement mix recorded 20.48 N/mm²; at 28 days, the control mix achieved 30.51 N/mm² compared to 28.27 N/mm² for the 10% replacement. Similarly, flexural strength values at 28 days decreased from 5.75 N/mm² for the control to 5.25 N/mm² at 10% replacement.

In conclusion, the experimental results indicate that increasing the replacement of coarse aggregate with crushed coconut shells results in a significant reduction in density, making the concrete lightweight and potentially more economical for pavement construction. However, higher replacement levels also lead to a gradual decrease in mechanical properties, with a marked deterioration observed beyond 10% replacement. The 10% replacement mix maintained mechanical properties closest to those of the control mix, with only a slight reduction in compressive strength (from 30.51 to 28.27 N/mm² at 28 days) and moderate decreases in flexural and split tensile strengths. These findings suggest that incorporating crushed coconut shells at an optimal percentage can effectively produce sustainable lightweight concrete suitable for rigid pavement construction in regions with abundant coconut waste.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of Study

The search for sustainable construction materials has gained significant momentum, fueled by both economic necessities and environmental concerns. This research is particularly relevant because it explores cost-effective, eco-friendly alternatives to conventional building materials. As noted by Olanipekun et al. (2006), the absorption capacity of an aggregate is a key indicator of its porosity, a crucial factor in the performance of construction materials. Materials scientists are continuously investigating the intricate physicochemical transformations that occur when plant waste is incorporated into building materials (Ramasubramani and Gunasekaran, 2021).

A particularly challenging and intriguing aspect of this research is determining the optimal proportions and compatibility of combining plant waste with mineral components, such as concrete. This is done to achieve the most effective and synergistic blend. Ramasubramani and Gunasekaran (2021), (Beskopylny *et al.*, 2023). The concept of sustainable development is under renewed scrutiny due to the growing challenge posed by the depletion of natural resources such as river sand and crushed stone. This issue has sparked intense discussions about the need for alternative materials that reduce environmental impact without compromising structural integrity.

Fortunately, technological advancements are paving the way for more sustainable concrete production, offering hope for a greener future.

One of the most promising solutions is the integration of renewable plant-based materials and industrial by-products into concrete. This approach not only minimizes the consumption of non-renewable resources but also addresses critical waste management challenges.

However, the key to successfully adopting such alternatives lies in ensuring that their strength and durability align with established construction standards. Among these potential substitutes, machined coconut shell stands out as a viable replacement for a portion of coarse aggregate in concrete. (Stel'makh *et al.*, 2023).

As a by-product of coconut processing, coconut shell presents an innovative and sustainable alternative for engineering applications. (Stel'makh *et al.*, 2023). Research has shown that incorporating waste materials into concrete can enhance structural durability by reducing early-age defects and prolonging the lifespan of buildings. By harnessing the potential of coconut shells in concrete production, this study aims to contribute to the growing movement toward more sustainable, efficient, and cost-effective construction solutions.

1.2 Statement of The Problem

The necessity for this research is multifaceted, stemming from critical issues in both resource management and environmental stewardship. Firstly, the escalating depletion of natural coarse aggregates, such as crushed stone and gravel, poses a formidable challenge. Their extraction is often ecologically damaging, contributing to habitat destruction and pollution, while increasing material costs and transportation distances. Simultaneously, the burgeoning accumulation of agricultural waste, specifically coconut shells, creates a significant environmental burden in many tropical regions. These shells, often discarded as landfill waste, consume valuable land and represent a massive underutilization of a readily available organic resource. Furthermore, while rigid pavements are known for their durability, their inherent density can present challenges, especially in areas with problematic subgrade conditions, thereby driving the quest for lightweight concrete solutions to reduce overall mass and improve handling.

The relevance of utilizing crushed coconut shells in rigid pavement construction is profound, offering a compelling pathway towards more sustainable and economical practices. Coconut shells possess characteristics that make them ideal for lightweight aggregate production due to their relatively low bulk density. Incorporating them into concrete can significantly reduce the pavement slab's overall weight, thereby lessening the load on the subgrade and potentially streamlining construction by making handling and transportation easier. However, concrete made with coconut shells must meet standard engineering performance criteria (workability, consistency, compressive strength, etc.)(Stel'makh *et al.*, 2023). Beyond weight reduction, this approach offers a substantial environmental dividend by transforming an agricultural waste product into a valuable construction material, championing the use of waste, and promoting a circular economy. Economically, in coconut-producing regions, their use as a partial aggregate replacement can notably reduce concrete production costs, leverage local resources, and strengthen regional economies.

In conclusion, this project is driven by the urgent need to address the dual challenges of finite natural resources and escalating waste generation within the construction industry. By meticulously evaluating the performance of lightweight concrete incorporating crushed coconut shells as a partial replacement for coarse aggregate, this study aims to provide a robust framework for developing sustainable and economically viable rigid pavement solutions. The transformative potential of coconut shells lies in their ability to reduce concrete density, repurpose agricultural waste, lower construction costs, and ultimately contribute to a more environmentally responsible and resource-efficient built environment, paving the way for future innovations in sustainable infrastructure

1.3 Aim and Objective of The Study

This study aims to evaluate the use of coconut shells as a coarse aggregate replacement in the construction of a rigid pavement.

The objectives of the study are:

1. Examine the physical and chemical properties of coconut shells and their compatibility with concrete used in rigid pavement.
2. Conduct experiments to determine the mechanical strength and properties of coconut shell concrete, and its potential to meet the demands of rigid pavement construction.
3. Conducting a comparative analysis of coconut shell modified concrete and conventional concrete.

1.4 Scope of Study

The scope of this work includes the following:

1. Examining the effects of coconut shells on the workability of concrete.
2. Mechanical Properties of Coconut Shells.
3. This study will conduct a comparative analysis of coconut shell modified concrete and conventional concrete through performance testing and evaluations, such as tensile strength test and flexural strength test.

1.5 Justification of Study

The construction industry urgently needs cost-effective, sustainable alternatives to traditional building materials. With the rising cost of crushed stone and other aggregates, coconut shells present an untapped opportunity to revolutionize rigid pavement construction. This study aims to prove that incorporating coconut shells into concrete not only reduces material costs but also provides an eco-friendly solution to waste management. If successfully implemented, this innovation could transform the way roads, highways, and infrastructure projects are built, making high-quality construction more accessible and affordable. Researchers have been seeking alternative materials to supplement traditional building materials. (Rahman *et al.*, 2020).

This study directly addresses three major industry concerns:

1. **Cost Savings** – Traditional aggregate materials are expensive and, in some regions, increasingly scarce. Using coconut shells, this study offers a low-cost alternative that reduces overall construction costs.
2. **Environmental Sustainability** – The construction industry contributes significantly to environmental degradation. Using agricultural waste, such as coconut shells, helps reduce landfill waste, conserve natural resources, and lower the construction industry's carbon footprint.
3. **Performance and Durability** – Rigid pavements require strong, long-lasting materials. This research seeks to validate the structural integrity of coconut shell concrete, ensuring that it meets or exceeds industry standards.

The insights from this study will provide a practical, scalable solution for engineers, contractors, and policymakers. This is not just an academic exercise; it is a step toward a greener, more affordable future in infrastructure development, one that governments, private investors, and environmental agencies should be eager to support.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter presents a comprehensive review of existing research related to sustainable construction materials, with a specific focus on the incorporation of coconut shell as a coarse aggregate in concrete. It explores key findings from previous studies, highlighting their contributions to the field of civil engineering and sustainable construction. The review is structured to examine the global demand for sustainable building materials, the potential of agricultural waste in concrete production, and the specific applications of coconut shell in construction.

2.1.1 The Need for Sustainable Construction Materials

Sustainability is a growing global concern, and the construction industry is a major contributor to environmental degradation through extensive extraction of natural aggregates. The demand for concrete, which continues to rise with infrastructure development, has raised concerns regarding the depletion of non-renewable resources and the ecological impact of mining activities (Mathur & Materials, 2006). In response, researchers have explored alternative materials, including industrial, domestic, and agricultural waste, as substitutes for traditional aggregates in concrete.

2.1.2 Coconut Shell as an Alternative Aggregate

Among the various agricultural waste materials investigated, crushed coconut shell has emerged as a viable alternative aggregate in concrete production. Research by Gunasekaran et al. (2013) highlights the potential of coconut shells to replace conventional coarse aggregates, offering an environmentally friendly and sustainable option for concrete production.

Adebakin et al. (2018) further investigated the use of coconut shell in self-compacting lightweight concrete. Their study revealed that concrete containing crushed coconut shell exhibited satisfactory flowability, viscosity, and passing ability. Additionally, incorporating 15% to 20% fly ash as a cement substitute further improved performance indicators such as permeability and water absorption (Jia et al., 2016).

2.1.3 Practical Applications of Coconut Shell in Construction

The practical application of coconut shells in structural and non-structural construction elements has been explored in various studies. Soumya et al. (2019) reported the successful use of coconut shell as coarse aggregate in the production of manhole cover slabs. Similarly, K. Gunasekaran et al. (2021) documented the manufacturing of hollow blocks using coconut shell aggregate, demonstrating its potential as a reliable and sustainable construction material.

2.2 Constituents of Concrete

Concrete remains the most widely utilized building material in modern construction due to its durability, versatility, and structural integrity. The fundamental components of concrete include binder (cement), aggregate, and water, each playing a crucial role in the material's overall performance (Alyamaç and Aydin, 2015). These ingredients interact chemically and physically to produce concrete in different stages, which can be classified as fresh, hardened, or green concrete.

1. **Fresh Concrete**: Fresh concrete refers to the state of concrete immediately after mixing, when it remains workable and compactable. At this stage, the mixture exhibits plasticity, allowing it to be poured, molded, and shaped into various structural forms. The workability of fresh concrete is a critical factor in determining its ease of placement and finishing. Proper mix design and water-cement ratio are

essential to achieving the desired consistency while maintaining strength and durability (Alyamaç and Aydin, 2015).

2. **Hardened Concrete**: Hardened concrete is the final, cured form of concrete that has achieved its intended strength and structural performance. Once the hydration process of cement is complete, the concrete solidifies into a dense, rigid material capable of bearing loads and resisting environmental factors. The strength of hardened concrete depends on various factors such as curing time, mix proportions, and aggregate properties. Proper curing is essential to ensure that hardened concrete attains the necessary compressive strength and durability required for construction applications (Alyamaç and Aydin, 2015).

3. **Green Concrete**: Green concrete refers to recently laid and consolidated concrete that has reached a stable state but has not yet undergone significant hardening. This phase occurs before noticeable strength development and is commonly referred to as "green concrete" in the pre-casting industry. At this stage, the concrete is still vulnerable to external disturbances, and proper handling is crucial to prevent deformation or cracking. The term "green concrete" is also used to describe environmentally friendly concrete that incorporates sustainable materials such as recycled aggregates or alternative binders (Alyamaç and Aydin, 2015).

2.3 Binder

Cement is the primary binding agent in concrete, ensuring cohesion between aggregates. It is produced through the high-temperature calcination of a carefully proportioned mixture of limestone and clay. This process occurs at temperatures ranging from 1400°C to 1500°C (Abdul-Wahab et al., 2019), depending on the production method and material composition. At these extreme temperatures, raw materials undergo complex chemical transformations, resulting in clinker, which is then ground into fine powder to produce cement.. When mixed with water, cement undergoes a chemical reaction known as hydration, which leads to setting and hardening. This transformation enables concrete to develop strength and durability in both air and underwater environments, making it a versatile material for a wide range of construction applications (Labidi and Megriche, 2022).

Cement is classified based on its hardening rate and resistance to environmental conditions. Different types of cement are used for specific applications depending on strength requirements, exposure conditions, and durability factors. The significant types of cement include: Ordinary Portland cement.

1. Ordinary Portland Cement (OPC): Ordinary Portland Cement is the most widely used type of cement in construction. It is suitable for general-purpose applications, offering high early strength development and reliable long-term durability.

2. Blast-furnace cement: Blast-furnace cement is produced by incorporating granulated blast-furnace slag, an industrial by-product from steel manufacturing. It enhances sulfate resistance, durability, and workability, making it suitable for marine structures and sulfate-rich environments.

3. Low Heat Cement: Low heat cement is designed explicitly for mass concrete structures where excessive heat generation could lead to cracking. It releases heat more slowly during hydration, making it ideal for dams, foundations, and other large-scale infrastructure projects.

Ordinary Portland cement is the most commonly used type of cement.

2.4 Coarse Aggregates

Coarse aggregates form the granular framework of concrete and consist primarily of gravel, stone, and sand. Their primary function is to provide structural stability, while the binder (cement) fills the voids between particles, ensuring cohesion. These aggregates contribute significantly to concrete composition, accounting for approximately 80% of its weight and 70-75% of its volume. (Nguyen *et al.*, 2014). To optimize concrete quality, it's crucial to select the right aggregate size and quality. Aggregates can be naturally occurring (from rivers or glaciers) or processed in industrial facilities using mechanical methods such as mixing, crushing, screening, and washing. The aggregate characteristics of density, porosity, and water absorption are a primary focus in determining the proper concrete mix. To be suitable for concrete, aggregates must not hinder cement hardening, form a strong bond with the hardened cement paste, and maintain the concrete's resistance. (Joshaghani *et al.*, 2014).

According to Crouch *et al.*, 2007, for aggregates to ensure durable concrete, they should possess:

1. High resistance to splitting and cracking
2. Strong resistance to wear and erosion
3. Low susceptibility to polishing and abrasion
4. Optimal particle density and water absorption rates
5. Suitable bulk density.

2.5 Types and Sources of Coarse Aggregates

Aggregates can be broadly classified based on their source:

1. **Naturally Occurring Aggregates**: Extracted from riverbeds, glaciers, and quarries, these aggregates are typically washed and screened before use in concrete production.

2. **Processed Aggregates**: Industrial processing methods such as crushing, screening, and mixing are used to refine aggregates for better quality control and uniformity.

For coarse aggregates to be suitable for concrete applications, they must not hinder cement hydration or compromise the integrity of the hardened mix. Their selection should ensure that concrete maintains compressive strength, weathering resistance, and long-term performance under various environmental conditions (Joshaghani et al., 2014). Proper grading and mixing techniques help optimize the distribution of aggregate particles, ensuring a well-compacted and high-strength concrete structure.

2.6 Water

In civil engineering, water plays a crucial role in the production of concrete. Globally, the concrete industry's processes, including casting, curing, and aggregate washing, consume over 1 billion tons of freshwater each year, making it a significant consumer of this precious resource.(More *et al.*, 2014). Mixing water is the water added to the concrete mix to create a workable paste. This water reacts with the cement to form a hardened gel-like substance. (Su *et al.*, 2002).

According to Peighambarzadeh *et al.*, 2020, water has the following functions in concrete production.

i. Hydration: Water reacts with cement to form a paste, which binds aggregates together, creating concrete.

ii. Workability: Water helps achieve the desired consistency and flowability of the concrete mix, making it easier to place and finish.

iii. Curing: Water is essential for the curing process, which involves maintaining a stable moisture environment to allow concrete to set and harden properly.

2.7 Properties of Concrete

2.7.1 Workability

Workability refers to the ease with which freshly mixed concrete can be handled and shaped, ensuring it can be placed, consolidated, and finished without issues. It also describes concrete's ability to resist segregation, in which the ingredients separate during transport and handling. A workable concrete mixture should maintain its uniform composition and consistency throughout the process. In high-performance concrete, workability encompasses the concrete's ability to flow freely and through tight spaces, known as filling ability and passing ability, respectively. This property is crucial for ensuring that the concrete can be easily placed and shaped without compromising its quality. Workability also involves the concrete's ability to resist separation during transport and placement — dynamic stability — and to maintain a uniform distribution of components after the concrete has stopped moving — static stability. By achieving optimal workability, concrete can be produced with consistent quality and performance. (Peighambarzadeh *et al.*, 2020).

2.7.2 Consistency

Concrete consistency is a strong indicator of its workability. A mix that is too dry and stiff will be challenging to work with, leading to potential separation of larger aggregate particles. Conversely, adding excessive water to achieve a more fluid mix can be counterproductive, leading to segregation, honeycombing, and reduced strength in the final product. Instead, the optimal consistency should be achieved, where the mix is workable without compromising its quality. (Peighambarzadeh *et al.*, 2020).

2.7.3 Uniformity

Uniformity is a crucial aspect of concrete quality, encompassing both within-batch and between-batch consistency. Inadequate mixing can lead to poor within-batch uniformity, which can be detected by comparing samples taken from the beginning and end of the batch. To achieve uniformity, consolidation is key. Vibration helps to mobilize the particles in freshly mixed concrete, reducing friction and giving the mixture a fluid-like consistency. Proper consolidation is significant for coarser or stiffer mixtures, as it significantly enhances quality and economy. Conversely, inadequate consolidation can result in weak, porous concrete with compromised durability (Peighambarzadeh *et al.*, 2020).

2.7.4 Durability

Concrete durability refers to its capacity to withstand various forms of degradation, including weathering, chemical damage, and wear, while retaining its intended structural properties. As a building material, concrete is exposed to a wide range of potentially damaging environmental conditions. The primary causes of concrete deterioration involve the movement of water or the presence of harmful substances, such as chlorides and sulfates, dissolved in water. Concrete with lower permeability is more resistant to deterioration, as it hinders the entry of damaging substances (Peighambarzadeh *et al.*, 2020). Freezing and thawing cycles can also cause deterioration, as the expansion of frozen water within the concrete creates damaging forces. Furthermore, corrosion of embedded steel reinforcement, often triggered by chloride penetration or carbonation, is a common issue in reinforced concrete structures, leading to premature deterioration.

2.8 Rigid Pavement

Pavement serves as a critical interface between the road's vehicle loads and the underlying foundation layers, transferring the weight and stress of traffic to the base layers. However, it's important to note that the foundation layers' ability to withstand these loads is not a primary consideration when determining the road's optimal alignment or route. Consequently, finding a pavement type that can withstand heavy traffic loads and mitigate settlement in the foundation layers is essential (Hajj *et al.*, 2010).

According to Gong *et al.* (2019), to ensure pavement durability, the surface layer must possess key characteristics, including water impermeability. Crucially, water seepage through cracks and holes can degrade the foundation layers and weaken the pavement's ability to support loads. Pavements can be categorized into two main types based on the material composition of their surface layers: flexible pavements and rigid pavements.
According to Topini *et al.* (2018), the type of material used for the surface layer is the primary factor in determining a road's classification. Flexible pavements are constructed using asphalt materials, and are commonly referred to as 'asphalt pavements'(Gautam *et al.*, 2018). Unlike concrete, asphalt pavements can absorb expansion and contraction movements without needing joints or breaks, tolerating a degree of deformation that can be recovered within a predetermined limit.(Busari *et al.*, 2019). Unlike asphalt, concrete pavements require a longer waiting period before they can be opened to traffic, as concrete needs adequate time to gain sufficient strength and cure.(Gautam *et al.*, 2018). It's essential to recognize that concrete pavements, or rigid pavements, typically consist of two main layers: a foundation layer and a surface layer, including the concrete slab. This slab provides fundamental support and reinforcement to the pavement and can be placed on either high-quality or low-quality foundation layers. (Swaddiwudhipong *et al.*, 2003). As the percentage of surface-layer cracks increases, so does the risk of dust and debris accumulation and, more critically, water infiltration into the foundation layers, leading to rapid degradation. It's worth noting that substandard concrete is a significant factor in the formation of these cracks, which can compromise pavement durability. (Tahir *et al.*, 2022).

Rigid pavements are a crucial component of modern infrastructure, providing durable and long-lasting surfaces for highways, airports, and other high-traffic areas. There are four primary categories of rigid pavement, each with distinct features, advantages, and applications.

2.8.1. Jointed Plain Concrete Pavement (JPCP) is the most basic type of rigid pavement, consisting of plain concrete slabs with joints to control cracking. This category is suitable for low-to-moderate traffic volumes, low-speed roads, parking lots, and shoulder pavements. JPCP has no reinforcement steel, and joints are spaced at regular intervals of 15-20 feet. The thickness ranges from 6 to 10 inches, making it cost-effective and easy to maintain. However, JPCP is prone to cracking and joint deterioration, limiting its load-carrying capacity.

2.8.2 Continuous Reinforced Concrete Pavement (CRCP) eliminates joints, reducing maintenance needs and providing excellent durability and load-carrying capacity. CRCP is suitable for high-speed, high-volume roads, airports, and heavy-duty industrial areas. With no joints, CRCP reinforcement steel is used throughout, with thicknesses ranging from 10 to 14 inches. Although CRCP has a higher initial cost and complex construction process, its reduced maintenance needs and improved ride quality make it an attractive option.

2.8.3 Pre-stressed Concrete Pavement (PCP) utilizes pre-stressed concrete to enhance strength and durability, making it suitable for heavy loads and high-traffic volumes. PCPs' cables or strands are tensioned before concrete hardening, improving resistance to cracking and faulting. With a thickness range of 8-12 inches, PCP offers enhanced strength and durability. However, PCP's higher initial cost and specialized construction equipment requirements limit its application.

Designing rigid pavements requires careful consideration of traffic volume, load, and material selection. Conducting thorough soil investigations and ensuring proper curing and finishing techniques are crucial. Regular inspections, joint repairs, and resurfacing are necessary to maintain pavement performance.

2.9 Coconut Shell

The coconut is the fruit of the coconut tree, a drupe containing prized flesh and water. Coconut shells are one of the by-products of the processing of coconuts. According to Janani *et al.* (2022), the coconut shell is an auspicious material, boasting exceptional strength and modulus. Its high lignin content enhances the durability and weather resistance of composites made from it. However, disposing of coconut shells poses a significant challenge, as they are classified as agricultural waste and require large areas for disposal after use, highlighting the need for sustainable utilization and management of this abundant resource. The porous structure of coconut shells, as observed under SEM, exhibits reservoir-like behavior. In coconut shell aggregate concrete, intermittent curing achieves superior strength compared to complete water curing and air-dry curing, indicating that regulated moisture levels enhance concrete performance. (K. Gunasekaran *et al.*, 2012). The crushed coconut shells used as a partial replacement material for lightweight concrete in this experiment were collected over time from fruit sellers along Ring Road, Benin City.

2.9.1 Chemical Composition of Coconut Shell

According to Whitehead (1980), the dry coconut shell aggregate has the following properties:

Table 2.1: Chemical Composition of Coconut Shells (Whitehead, 1980)

COMPOUND	PERCENT
Lingnin	36.51
Cellulose	33.61
Ash	0.61
Pentosans	29.27

2.9.2 Layered Structure of Coconut

The rugged, woody shell that encases the seed, known as the endocarp, serves as the primary structural component and protective barrier. This shell is primarily composed of cellulose, hemicellulose, and lignin, with minor amounts of pectin and proteins, which collectively provide its strength and durability. (Gludovatz *et al.*, 2017). The remaining two sections consist of a dense, fibrous husk (coir) enveloped in a slender, fragile outer layer (exocarp). However, our focus lies with the globular endocarp, a sturdy, wooden shell that serves as the seed's central framework and defense mechanism.

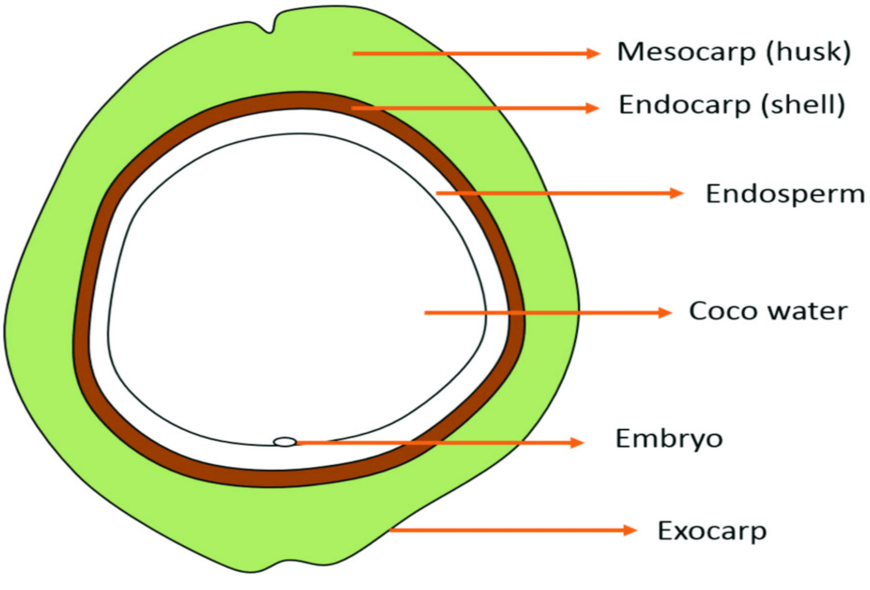

Figure 2.1: Transverse structure of coconut fruit (Gludovatz et al., 2017)

After crushing, the shells are flaky and irregularly shaped. The concrete obtained with Coconut Shell aggregates meets the minimum requirements for lightweight concrete. (Gunasekaran *et al.*, 2012).

Figure 2.2: Crushed coconut shells (CS) (Gunasekaran et al., 2012).

CHAPTER THREE

3.0 METHODOLOGY

This chapter presents the experimental procedures and findings for the materials utilized in this study, including ordinary Portland cement, river sand, crushed stone, and coconut shell aggregate. It provides a detailed account of the tests conducted on these materials and the corresponding results.

3.1 Materials

The materials used in this study include:

1. Cement
2. Coarse aggregate (granite)
3. Fine aggregate (sand)
4. Coconut shell
5. Water.

3.1.1 Coarse and Fine Aggregates

Crushed stone, gotten from a commercial quarry, coconut shells from the local market, and natural river sand are the fine aggregates.

Aggregates can be classified as follows:

1. **Classification according to geological origin:** Aggregates typically originate from natural sources and may be found in their required size or require crushing to achieve the desired size. These aggregates can be broadly categorized into two main types: natural and artificial.

Natural aggregates are derived from naturally occurring deposits, such as sand and gravel found in rivers, lakes, or ocean beds. They can also be obtained through quarrying, where rocks are extracted and processed to produce the desired aggregate size. This type of aggregate is widely used in construction due to its availability and cost-effectiveness. On the other hand, artificial aggregates are manufactured from various materials. These may include industrial by-products, such as air-cooled blast furnace slag, or recycled materials, such as crushed bricks. Artificial aggregates offer a sustainable alternative to natural aggregates, reducing waste and conserving natural resources.

The distinction between natural and artificial aggregates is crucial because it shapes their properties, uses, and environmental impacts. Understanding the origin and characteristics of aggregates is essential in selecting the appropriate type for specific construction applications, ensuring durability, sustainability, and structural integrity.

2. **Classification according to size**: Aggregates are classified based on their size into three primary categories: fine aggregate, coarse aggregate, and all-in-aggregate. The maximum aggregate size can vary, but particles from different size fractions must be combined in the mix in suitable proportions.

Fine aggregates typically consist of smaller particles, with sizes ranging from fine sand to coarse sand. Coarse aggregates, on the other hand, comprise larger particles, such as gravel or crushed stone. All-in-aggregate, as the name suggests, is a blend of both fine and coarse aggregates. Regardless of the aggregate type, proper grading is crucial to ensure optimal performance in construction applications. Grading involves combining particles of various sizes in appropriate proportions to achieve a balanced mix. This balance is critical to maintaining concrete's strength, durability, and workability.

Effective grading enables the aggregate particles to pack efficiently, reducing voids and minimizing the need for excess cement or water. This, in turn, enhances the overall quality and sustainability of the concrete structure. Consequently, careful attention to aggregate sizing and grading is essential in construction projects to guarantee successful outcomes.

3. **Classification based on unit weight:** Aggregates can also be categorized based on their unit weights into three distinct groups: normal weight, heavy weight, and light weight aggregates.

3.1.2 Cement

Ordinary Portland Cement (OPC) was the material used in this study. The chemical composition and basic engineering properties of the OPC according to Tran and Phan (2024) Is shown below.

Table 3.1: Chemical Composition of OPC (Tran and Phan, 2024)

CHEMICALS	PERCENTAGE (%)
SiO_2	21.65
AL_2O_3	5.25
Fe_2O_3	3.42
CaO	65.00
MgO	0.06
Na_2O_3	0.25
K_2O	0.72
SO_3	1.80
Free CaO	0.125

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Table 3.2: Basic Physical Properties of OPC (Tran and Phan, 2024)

Specific gravity (g/cm3)		**3.1**
Compressive strength (MPa)	3 days	28.40
	28 days	52.5
Flexural strength (MPa)	3 days	5.8
	28 days	8.6
Setting time (min)	Initial	120
	Final	225

3.1.3 Coconut Shell

A waste product that is widely available in Nigeria will be used as a partial replacement for cement. This was gotten from Uselu Market and Ring Road, Benin City, Edo State.

3.1.4 Water

Potable water was used for mixing, which was obtained from the tap in the civil engineering laboratory, University of Benin.

3.2 Test Methods

3.2.1 Workability

The ability of freshly mixed concrete to be easily placed, compacted, and finished without separating excessively during construction is known as workability. A widely used technique for assessing workability is the slump test, which measures the deformation of a compacted concrete cone after it has been layered three times. This test evaluates how well the concrete maintains its shape and consistency under various construction conditions. ASTM C143 (ASTM, 2012) was employed to determine the slump test. In this, the mold, measuring 300 mm in height, with a bottom diameter of 200 mm and a top diameter of 100 mm, is open at both ends and positioned on a flat, smooth, and impermeable surface. The concrete mixture is prepared and poured into the mold in three separate layers, with each layer being compacted using 25 tamping strokes. The slump is then calculated by measuring the vertical difference between the mold's original height and the concrete's height after the mold is lifted, thereby providing the concrete's settlement.

3.2.2 Setting Time

The setting time is the period during which cement becomes workable and can be used in construction projects. This timeframe is typically divided into two stages: the initial setting time, which marks the beginning of the hardening process, and the final setting time, which indicates its completion. Using ISO 9597 according to Ghoddousi *et al.* (2016), the Vicat apparatus is employed to determine the setting times of cement. The process begins with preparing a cement paste by combining a precise amount of cement with a predetermined amount of water. Subsequently, the initial set time is measured with a small needle, and the final set time is determined with a larger needle, providing a clear indication of the cement's hardening progression.

3.2.3 Compressive Strength Test

Compressive strength test performed according to ASTM C39. (Concrete and Aggregates, 2014)The strength of the specimen was measured using a San 3000 electronic compressor with a maximum capacity of 3000 kN. During the test, the load was increased at 0.3 MPa/s to apply a controlled amount of pressure, enabling an accurate assessment of the specimen's compressive strength. The final result represents the average compressive strength of three identical samples tested under the same conditions.

3.2.4 Slump Test

The slump test was conducted to determine the workability of fresh concrete, as outlined in BS 1881-103:1983. The concrete sample was obtained from the mixing truck and thoroughly mixed to ensure uniformity. The retained quarters were mixed and quartered in the same way as the original sample. This process was continued until the desired quantity was obtained. The unused portion of the original field sample was saved until all testing exercises were completed, in case retesting was needed.

The following apparatus was used: a slump cone (300mm height, 100mm base diameter, 200mm top diameter) conforming to BS 1881-103:1983, a tamping rod (600mm long, 16mm diameter), a leveling plate, a measuring staff or ruler, and concrete mixing and testing equipment.

3.2.4.1 Testing Procedure

1. The slump cone was moistened and placed on the leveling plate.
2. The concrete sample was then filled into the slump cone in three layers, each approximately 100mm deep. After filling each layer, the concrete was compacted with 25 strokes of the tamping rod, using a circular motion and distributing it evenly over the surface.
3. Once the third layer was compacted, the excess concrete was struck off with a trowel or straight edge, ensuring the surface was level with the top of the cone. The slump cone was then carefully removed by lifting it vertically, taking care not to disturb the concrete.

The slump was measured as the difference between the original height of the cone (300mm) and the settled height of the concrete, using a measuring staff or ruler. The slump value was recorded and classified in accordance with BS 1881-103:1983. The slump values were categorized as follows: true slump, 0-40mm, indicating low workability; collapse slump, greater than 40mm to 80mm, indicating medium workability; and shear slump, greater than 80mm, indicating high workability. The test results, including the slump value, concrete mix design, and testing conditions, were documented for future reference. Throughout the testing process, the testing area was kept clean, level, and free of vibrations. The slump cone and tamping rod were cleaned and moistened between tests. The concrete temperature was maintained between 15°C and 25°C. Testing was completed within 30 minutes of mixing.

3.2.5 Method for Determination of Compressive Strength of Concrete Cubes (BS 1881:Part 116:1983)

The objective of BS 1881: Part 116:1983 is to specify a method for determining the compressive strength of concrete cubes. The following apparatus was used:

1. Concrete cube moulds, either 100mm or 150mm, conforming to BS 1881-108:1983
2. Compression testing machine, capable of applying a load at a specified rate
3. Calibration equipment
4. Measuring instruments

3.2.5.1 Testing procedure

1. The concrete cubes were prepared and cast in accordance with BS 1881-108:1983. The cubes were then cured in a controlled environment, ensuring a consistent temperature and humidity.
2. After 24 hours, the cubes were demoulded and stored in water or a controlled environment until testing.
3. Before testing, the cubes were measured to determine their dimensions.
4. The cubes were then placed in the compression testing machine, ensuring proper alignment.
5. A load was applied at a specified rate, typically between 0.5 and 1.0 MPa/s, until failure occurred.
6. The maximum load was recorded, and the compressive strength was calculated.

The compressive strength was calculated as the maximum load divided by the cube's cross-sectional area.

3.2.6 Determination of Flexural Strength (BS 1881-117:1983)

The objective of BS 1881-117:1983 is to specify a method for determining the flexural strength of concrete beams, providing a measure of the material's ability to withstand bending forces. The following apparatus was used:

1. Concrete beam moulds, typically 100mm x 100mm x 500mm conforming to BS 1881-108:1983
2. Testing machine capable of applying a load at a specified rate

3. Calibration equipment
4. Measuring instruments

3.2.6.1 Procedure

1. The concrete beams were prepared and cast in accordance with BS 1881-108:1983. The beams were then cured in a controlled environment, ensuring a consistent temperature and humidity.
2. After twenty-four hours, the beams were demoulded and stored in water or a controlled environment until testing.
3. A load was applied at a specified rate, typically between 0.05-0.1 MPa/s, until failure occurred.
4. The load and corresponding deflection were recorded.
5. The flexural strength was calculated using the formula: Flexural strength = (Maximum load x Span) / (Cross-sectional area x Depth squared)

3.2.7 Determination of Splitting Tensile Strength According To (BS 1881-118:1983)

The objective of BS 1881-118:1983 is to specify a method for determining the splitting tensile strength of concrete, providing a measure of the material's ability to withstand tensile forces. The following apparatus was used:

1. Concrete cylinder moulds (typically 100mm or 150mm diameter x 200mm or 300mm height)
2. Testing machine capable of applying a diametrical load
3. Calibration equipment
4. Measuring instruments.

3.2.7.1 Procedure

1. The concrete cylinders were prepared and cast in accordance with BS 1881-108:1983.

2. The cylinders were cured in a controlled environment, ensuring a consistent temperature and humidity.
3. After twenty-four hours, the cylinders were demoulded and stored in water or a controlled environment until testing.
4. Before testing, the cylinders were measured to determine their dimensions.
5. A diametrical load was applied at a specified rate until failure occurred.
6. The load and corresponding deformation were recorded.

The splitting tensile strength was calculated using the formula:

Splitting Tensile Strength = (2 x Maximum load) / (π x Diameter x Thickness).

The test results, including the average splitting tensile strength, individual cylinder strengths, and standard deviation, were documented and reported.

3.3 Testing Aggregates Method for Determination of Abrasion Value (BS 812-113:1990)

Objective: To determine the abrasion value of aggregates, which measures their resistance to wear and abrasion.

Scope: This standard applies to natural and crushed aggregates passing through a 14mm sieve and retained on a 10mm sieve.

3.3.1 Equipment

1. Agate or porcelain mortar and pestle
2. Abrasion testing machine
3. Sieves (14mm, 10mm, 5mm, 2.36mm, 1.18mm, 600µm, 300µm, 150µm)
4. Oven
5. Balance

3.3.2 Test Procedure

1. The field sample was reduced to a suitable size through quartering. The retained quarters were mixed and quartered in the same way as the original sample. This process continued until the desired quantity was obtained. The unused portion of the original field sample was saved until all testing exercises were completed, in case retesting was needed.
2. The retained aggregates were air-dried and set aside for sieving. The aggregates were then sieved through a series of sieves to determine the particle size distribution.
3. A 5kg sample of aggregate passing through a 14mm sieve and retained on a 10mm sieve was prepared. The sample was washed, dried, and placed in the abrasion testing machine.
4. The machine was operated for 1000 revolutions at a speed of 30-40 rpm. The abraded aggregate was then washed, dried, and weighed.

Table 3.3: Aggregate Crushing Value for Coarse Aggregate

COARSE AGGREGATE	FORMULA	ACV	QUALITY ASSESSMENT
Sample 1	(W_3/W_2-W_1) *100	<30%	Road with Heavy Traffic
Sample 1	(W_3/W_2-W_1) *100	Up to 45%	Other Road Surfaces

3.4 Testing Aggregates Methods for Sampling and Testing of Aggregate (BS 812-102:2015)

The sampling and testing of aggregates were conducted in accordance with BS 812-102:2015 to ensure representative test samples. The objective of this standard is to specify methods for sampling and testing aggregates to ensure representative test samples for construction purposes.

3.4.1 Apparatus

The following apparatus was used: sampling equipment, such as scoops and augers; sampling containers; sieves conforming to BS 410:2000; a balance accurate to 0.1%; an oven capable of maintaining a temperature of 105°C ± 5°C; and a desiccator.

3.4.2 Sampling Procedure

1. The sampling location was selected to represent the entire batch, taking into consideration factors such as aggregate type, size, and moisture content. The sampling equipment was cleaned and prepared before use.
2. The aggregate sample was obtained by taking a minimum of three to five samples from different locations within the batch. Each sample was collected using the sampling equipment, ensuring that the entire batch was represented.
3. The samples were then combined to form a composite sample, which was thoroughly mixed to ensure uniformity. The retained quarters were mixed and quartered in the same way as the original sample. This process was continued until the desired quantity was obtained.
4. The unused portion of the original field sample was saved until all testing exercises were completed, in case retesting was needed.

3.4.3 Test Portion Preparation

1. The retained aggregates were then air-dried and set aside for sieving. The test portion was dried to constant mass in an oven at 105 ± 5°C.
2. After drying, the test portion was cooled in a desiccator to prevent moisture absorption. The weight of the test portion was recorded to the nearest 0.1%.

3.4.4 Sieve Analysis

1. The test portion was then sieved using sieves conforming to BS 410:2000. The sieves were arranged in descending order of aperture size, and the aggregate was sieved for a minimum of 10 minutes.
2. The weight of each size fraction was recorded, and the percentage passing each sieve was calculated.

3.4.5 Additional Procedures

1. Additional procedures were conducted in accordance with relevant British Standards, including washing (BS 812-103:2015), crushing (BS 812-110:1990), and flakiness index (BS 812-105:1990).

3.4.6 Important Details

1. Throughout the sampling and testing process, the following essential details were considered:
2. The sampling frequency depended on the batch size, with larger batches requiring more frequent sampling.
3. The test portion size was a minimum of 2 kg for coarse aggregates and 1 kg of fine aggregates.
4. The sieve sizes ranged from 63 µm to 125 mm.
5. Accuracy and precision of results were ensured through proper calibration and maintenance of equipment.

3.5 Concrete Mix Design Using (COREN 2016/017/RC)

For this research, concrete with a strength of 30 MPa was used to construct the rigid pavement. The design mix is carried out as follows:

1. Determination of Target Mean Strength

To account for production variations in concrete, the mix design must incorporate a strength buffer above the required characteristic strength, with the target compressive strength determined by Equation 1.

$F_m = F_c + Ks$

where Fm = the target mean strength m

Fc = the specified characteristic ‘c’ strength

K = a constant (taken as 1.64 for a 5% defective level)

s = standard deviation

To accurately determine standard deviation, a minimum of 20-30 concrete samples should be tested on-site as early as possible. If there are substantial changes in batch production, new calculations are necessary. According to COREN (2017), the recommended standard deviation is 6 Nmm-2, but producers are encouraged to use a lower value if test results indicate.

Margin = k x standard deviation = 1.64 x 6 = 9.84 N/mm^2

Target mean strength = characteristic strength + margin = 30 + 9.84 = 39.84 N/mm^2

2. Water to Cement ratio:

The compressive strength of concrete can be influenced by different cements and aggregates, even at the same water-cement ratio. To ensure optimal performance, determine the strength-water-cement ratio relationship for the specified materials. Then, verify the selected ratio against the maximum allowable for durability and use the more conservative value.

Figure 3.1: Strength versus Water/Cement Ratio for Nigerian Cements

The chosen water/cement ratio should be verified against the maximum ratio required for durability, and the lower value should be adopted. Alternatively, equations linking target mean strength to water/cement ratio can be used for Nigerian cement grades 32.5 and 42.5.

For grade 32.5, $r = (62 – \sigma)/64$ (1)

For grade 42.5, $r = (83 – \sigma)/84$ (2)

Where,

σ = target mean strength

r = water/cement ratio

These formulas have limitations:

For grade 32.5, the target mean strength is limited to 44 N/mm^2 for a water/cement ratio between 0.3 and 0.9; otherwise, the limit is 52 N/mm^2

For grade 42.5, the target mean strength is limited to 57 N/mm^2 for a water/cement ratio between 0.3 and 0.9; otherwise, the limit is 68 N/mm^2

3. Determination of Water Content

The water content of concrete depends on the type and maximum aggregate size to achieve a specific workability. This manual addresses two slump ranges: 30-60mm and 60-180mm, with maximum aggregate sizes limited to 20mm and 40mm. The recommended water content for these combinations is shown in Table 3.3 below.

Table 3.3: Approximate Free water contents required to give various levels

Maximum size of coarse aggregate	**Aggregate Type**	**Slump 30-60mm**	**Slump 60-180mm**
20	Uncrushed	180	205
	Crushed	210	235
20	Uncrushed	160	185
	Crushed	190	215

4. Determination of Cement Content

The cement content is determined from the water-cement ratio and the quantity of water.

$$Cement\ content = \frac{free\ water\ content}{free\ water/cement\ ratio}$$

The calculated value is checked against the specified cement content range. If it exceeds the maximum, upgrade to a higher cement grade. If it falls below the minimum, adopt the minimum value and adjust the water content to maintain the desired water/cement ratio. Superplasticizers can be used to meet requirements without changing cement content.

5. Determination of Aggregate Content

To calculate the total aggregate content, an accurate estimate of the fully compacted concrete's density is required. A recommended density value of 2400kg/m3 is suggested for all normal-weight aggregate mixes. The total aggregate content can be determined using a specific relationship.

The fine- and coarse-aggregate proportions are then derived from the total aggregate content. However, due to the unique characteristics of Nigerian quarry products, which often fall outside BS882 coarse aggregate standards, a combined aggregate grading envelope is advised. Two methods are proposed for determining the optimal proportion of fine aggregates in concrete.

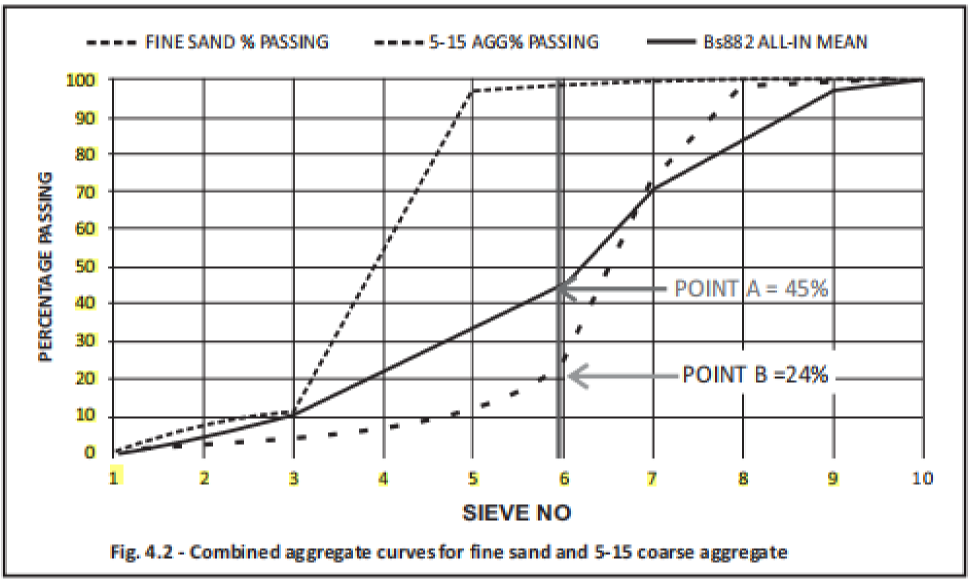

Figure 3.2: Combined aggregate curves for fine sand and 5-15 coarse aggregate

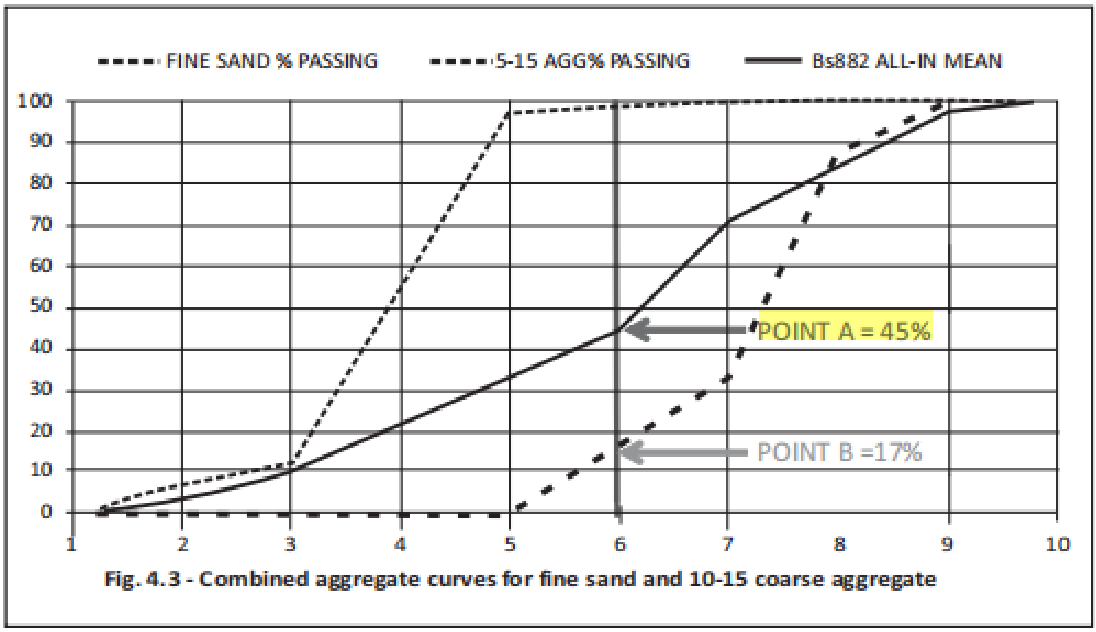

Figure 3.3: Combined aggregate curves for fine sand and 10-15 coarse aggregate

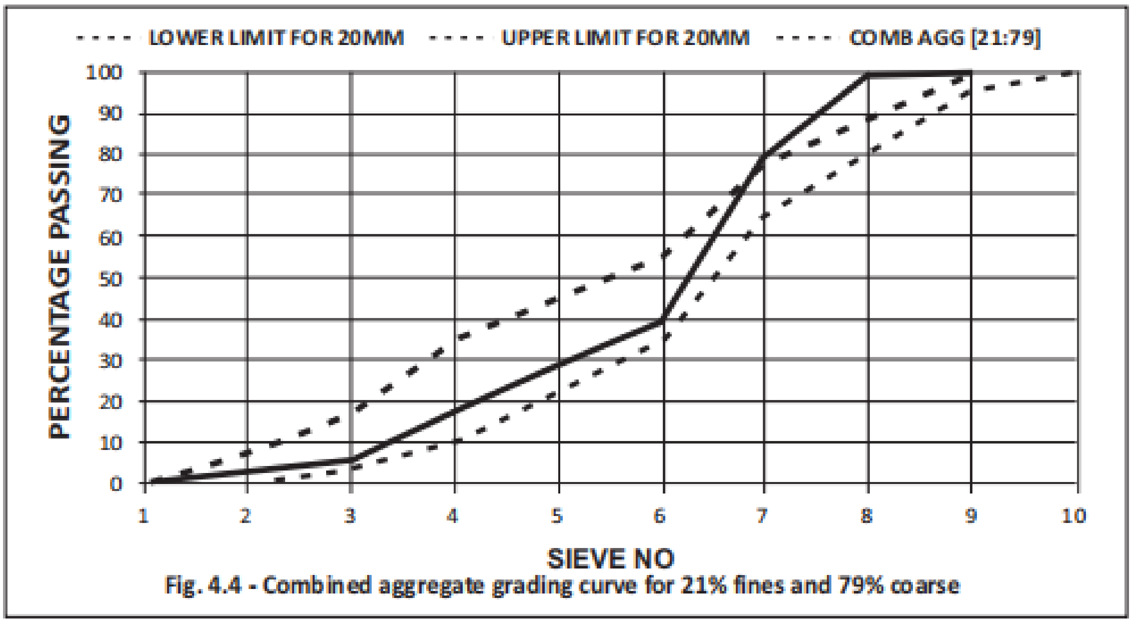

Figure 3.4: Combined aggregate grading curve for 21% fines and 79% coarse

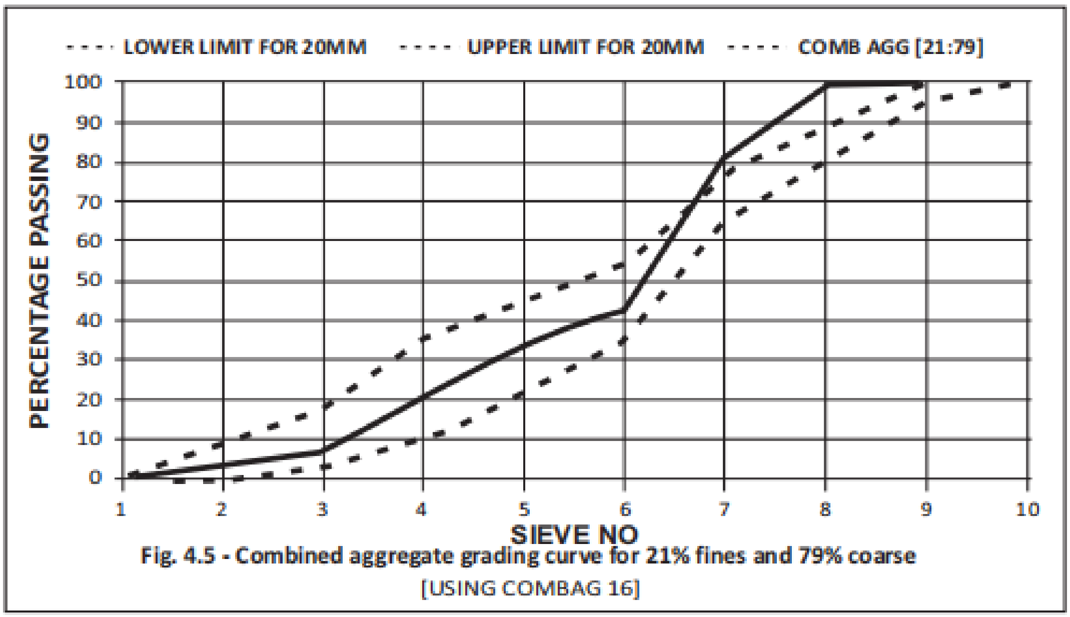

Figure 3.5: Combined aggregate grading curve for 21% fines and 79% coarse

The first method involves overlaying the fine- and coarse-aggregate grading curves on a single graph. The objective is to find the optimal combination of fine and coarse aggregates that yields a grading curve closely aligned with the median of the BS882 envelope.

CHAPTER 4

4.1 RESULTS AND DISCUSSION

This chapter discusses the results and analyzes the tests conducted during this project.

4.2 Results

Aggregate Particle Size Distribution Analysis. Sieve analysis is used to assess the particle size distribution within an aggregate sample, commonly known as gradation. An ideal particle size distribution indicates that the aggregate sample includes all standard size fractions in the necessary proportions, resulting in minimal void spaces. The primary purpose of analyzing particle size distribution is to obtain well-graded aggregates, which directly affect the workability of the concrete produced.

4.3 Analysis of Particle Size Distribution for Normal Crushed Stone Aggregate

A coarse aggregate with a nominal size of 12 mm was used for this particle size distribution analysis. Evaluating the particle-size distribution of coarse aggregate is crucial to ensuring optimal concrete workability and compatibility. The results are provided below.

Table 4.1: Crushed Stone Aggregate Particle Size Distribution

SIVE SIZE	PERCENTAGE PASSING CUMMULATIVE
19.0	100.0
13.20	85.0
10.00	37.5
8.00	10.0
4.75	2.50
PAN	0.0

4.4 ACV (Aggregate Crushing Value) Test

The ACV test is significant because it ensures the durability and stability of road layers. It helps engineers select the appropriate aggregate type for different layers of road construction, ultimately contributing to the safety and longevity of pavement structures. By determining the crushing strength of aggregates, the ACV test plays a crucial role in maintaining the quality and performance of road infrastructure.

Weight of empty cylinder= 15kg (W_1)

Weight of residue + Cylinder= 18kg (W_2)

Weight of Crushed Aggregate passing through 2.36mm sieve= 0.69kg (W_3)

Weight of Aggregate collected before crushing = 3kg

Table 4.2: Aggregate Crushing Value for Coarse Aggregate

COARSE AGGREGATE	FORMULA	ACV	QUALITY ASSESSMENT
Sample 1	(W_3/W_2-W_1) *100	23%	good

The Aggregate Crushing Value (ACV) test is an important parameter used to determine the strength and durability of aggregates in road construction and other civil engineering projects. This test provides a relative measure of an aggregate's resistance to crushing under gradually applied compressive loads. By assessing the aggregate's crushing strength, the ACV test helps engineers evaluate its suitability for use in various layers of road pavement.

In conducting the ACV test, a specific procedure is followed. First, the aggregate sample is sieved through a 12.5 mm sieve and retained on a 10 mm sieve. About 3 kilograms of this sieved sample is weighed and placed in a cylindrical mold. The aggregate is then compacted using a tamping rod to ensure uniform density. Once prepared, the filled mold is subjected to a compressive load of 40 tons, applied gradually over 10 minutes. This process aims to simulate the crushing effect experienced by aggregates under actual road traffic conditions.

After loading, the crushed material is sieved through a 2.36 mm sieve to separate the fines generated during the test.

A lower ACV indicates that the aggregate is stronger and more resistant to crushing, making it suitable for use in road layers subjected to heavy traffic. Conversely, a higher ACV signifies weaker aggregates that may not be appropriate for load-bearing applications. For roads with heavy traffic, the ACV should be less than 30 percent; for other road surfaces, an ACV of up to 45 percent is acceptable.

4.5 Slump Test

Test results from the slump test carried out are as follows

Table 4.3: Slump Test Results

PERCENTAGE OF COARSE AGGREGATE REPLACED	SLUMP VALUE (mm)
0% CS replacement	55
10% CS replacement	63
15% CS replacement	71
20% CS replacement	82
25% CS replacement	90
30% CS replacement	95

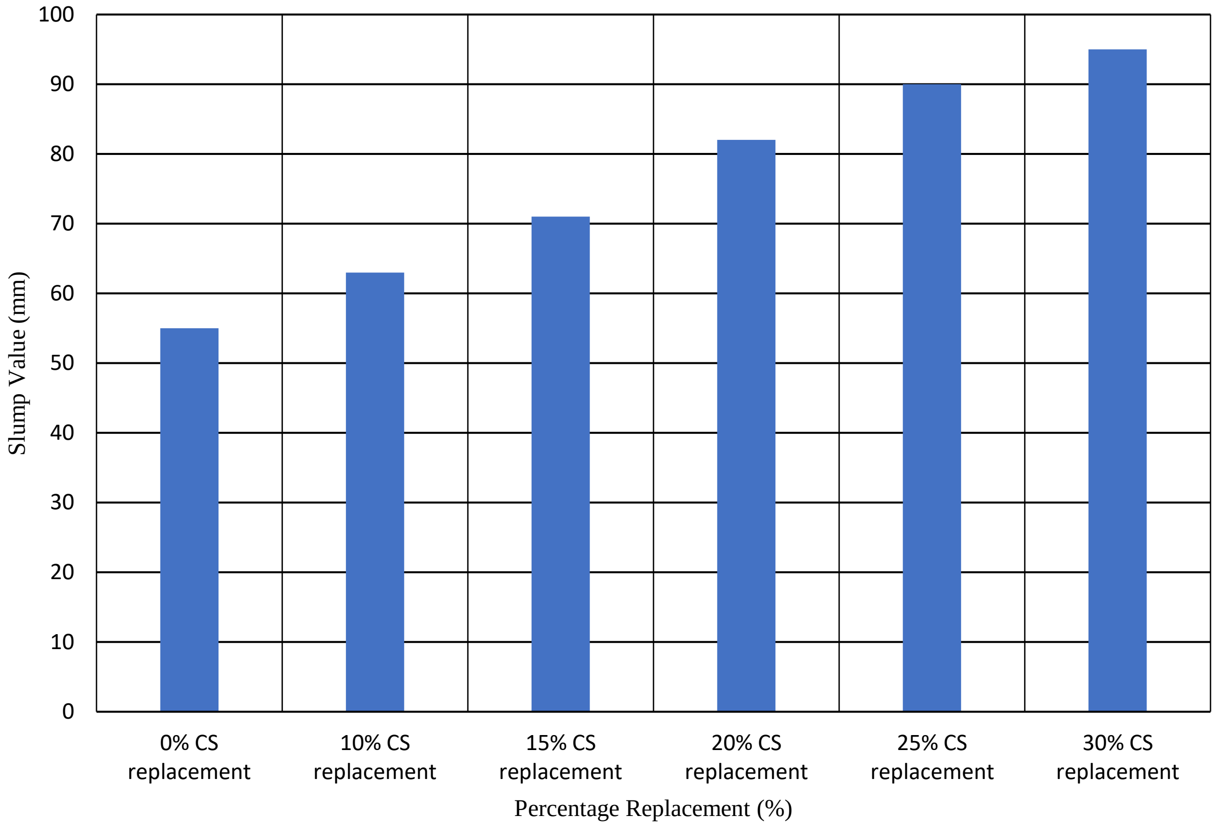

Figure 4.3 Comparative chart variation of the slump of concrete with CS replacement

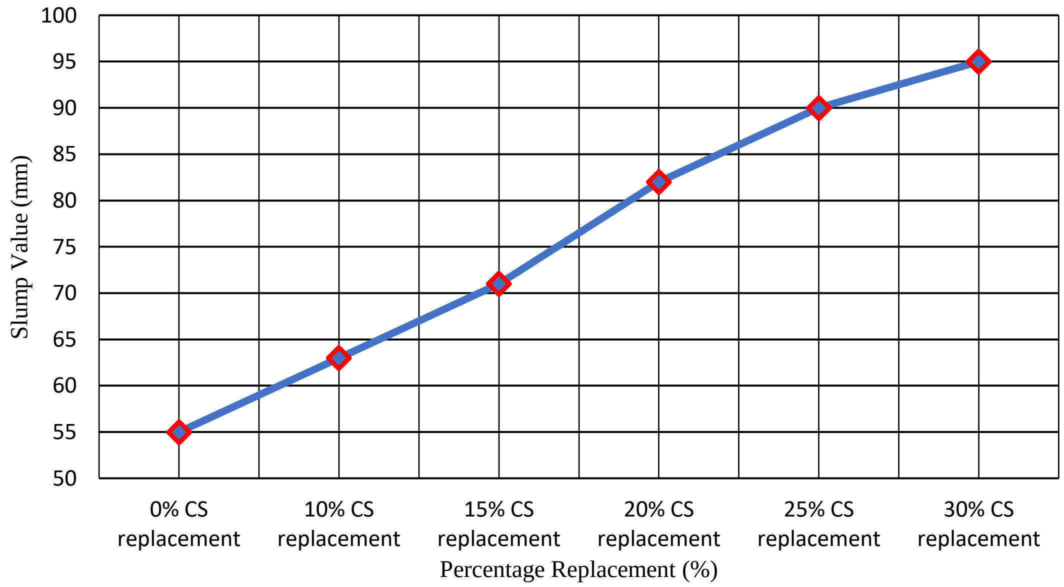

Figure 4.2 comparative graph variation of the slump of concrete with CS replacement

The slump test is a widely used method in civil engineering to measure the consistency and workability of fresh concrete before it sets. It indicates the ease with which concrete can be mixed, placed, compacted, and finished without segregation or bleeding. This test is essential for ensuring that the concrete mix has the desired fluidity and cohesiveness needed for specific construction applications.

To perform the slump test, a standardized procedure is followed: freshly mixed concrete is placed in a conical metal mold known as a slump cone, which is open at both ends and 300 mm high. The cone is placed on a non-absorbent, flat surface, and the concrete is filled in three layers, each approximately one-third of the height of the cone. After placing each layer, it is tamped 25 times using a tamping rod to eliminate air voids and ensure uniform compaction. Once the cone is completely filled and leveled, it is carefully lifted vertically, allowing the unsupported concrete to slump or settle under its own weight.

The amount of slump is then measured as the difference in height between the top of the slump cone and the highest point of the slumped concrete. This measurement indicates the workability and consistency of the concrete mix. There are three general types of slumps: true slump, shear slump, and collapse slump. A true slump maintains its overall shape while subsiding slightly, indicating a workable, cohesive mix. A shear slump occurs when part of the concrete shears off and slips to one side, often signaling segregation or insufficient cohesiveness. A collapse slump occurs when the concrete completely collapses, indicating a mix that is too wet and unstable.

The results of the slump test are interpreted in accordance with the project's requirements. A low slump value indicates a stiff, dry mix suitable for pavements or heavy foundations. In contrast, a high slump value suggests a more fluid mix, ideal for structures with complex formwork or high reinforcement density. Generally, a slump range of 25 to 75 mm is recommended for reinforced concrete structures, while a range of 50 to 100 mm is used for general construction work. The slump test is crucial in quality control for concrete construction, ensuring the mix has the proper workability without compromising strength or durability.

By assessing the consistency of fresh concrete, the slump test helps engineers and contractors make on-site mix adjustments, preventing issues such as segregation, bleeding, or honeycombing in the finished structure. This simple yet effective test is a fundamental tool for maintaining the quality and integrity of concrete construction.

4.6 Compressive Strength of Concrete

The results of the compressive strength test at 7, 14, and 28 days are presented in the tables below:

Table 4.4: Compressive strength test results after 7 days curing

COMPRESSIVE STRENGTH (7 DAYS)								
Percentage of replacement	**Cube No. (kN)**			**Average Strength (kN)**	**Weight of Cube (kg)**			**Strength =F/A (A=100*100=10,000)**
	1	2	3		1	2	3	
0%(Control)	209.33	213.10	210.30	210.9	2.65	2.60	2.65	21.09
10%	225.90	196.72	191.62	204.75	2.50	2.50	2.45	20.48
15%	202.58	118.73	177.24	166.18	2.60	2.45	2.60	16.62
20%	187.41	111.15	107.49	135.35	2.45	2.60	2.60	13.54
25%	151.33	143.46	93.16	129.32	2.65	2.55	2.60	12.93
30%	89.52	101.92	94.60	95.35	2.35	2.35	2.40	9.54

Results obtained from the Compressive Strength for 14 days of curing.

Table 4.5: Compressive strength test results after 14 days curing

COMPRESSIVE STRENGTH (14 DAYS)								
Percentage of replacement	**Cube No. (kN)**			**Average Strength (kN)**	**Weight of Cube (kg)**			**Strength =F/A (A=100*100=10,000)**
	1	2	3		1	2	3	
0%(Control)	243.00	234.50	240.55	239.4	2.55	2.50	2.55	21.94
10%	230.20	225.14	228.04	227.67	2.50	2.50	2.50	20.48
15%	215.10	210.03	212.11	212.33	2.55	2.55	2.55	18.80
20%	200.06	195.13	198.15	197.67	2.50	2.50	2.50	17.87
25%	185.22	180.03	183.47	182.67	2.60	2.55	2.60	16.80
30%	160.33	165.20	162.18	162.83	2.45	2.55	2.45	14.59

Results obtained from the Compressive Strength for 28 days of curing

Table 4.6: Compressive strength test results after 28 days curing

COMPRESSIVE STRENGTH (28 DAYS)								
Percentage of replacement	**Cube No. (kN)**			**Average Strength (kN)**	**Weight of Cube (kg)**			**Strength =F/A (A=100*100=10,000)**
	1	2	3		1	2	3	
0%(Control)	293.50	311.20	310.50	305.07	2.60	2.55	2.55	30.51
10%	283.55	280.22	285.16	282.67	2.55	2.55	2.50	28.27
15%	275.03	270.12	272.43	272.33	2.50	2.55	2.50	27.23
20%	260.82	254.97	257.06	257.67	2.50	2.50	2.50	25.78
25%	240.14	235.71	238.08	237.67	2.50	2.50	2.45	23.81
30%	220.18	215.34	218.07	217.67	2.45	2.45	2.50	21.77

The compressive strength of the concrete was tested to ensure that it met the required standards for structural integrity and safety. This test was crucial because compressive strength determines the concrete's ability to withstand loads without cracking or failing, which is essential for the stability and durability of the constructed elements.

To carry out the test, we prepared concrete cubes measuring 150 mm on a side in accordance with the standard testing guidelines. These samples were taken from the same concrete batches used in construction to represent the in-situ material accurately. After molding, the cubes were compacted thoroughly to eliminate any air voids that could affect the strength results. They were then allowed to cure under controlled conditions by immersion in water at 27°C. Curing was done for 7, 14, and 28 days, as these time intervals are standard for assessing the progressive strength development of concrete.

Once the curing periods were completed, the cubes were tested using a compression testing machine. Each specimen was placed in the machine, and a steadily increasing load was applied until the concrete cube failed by cracking or crushing. The maximum load at which each specimen failed was recorded, and the compressive strength was calculated by dividing this load by the cross-sectional area of the cube.

The successful compressive strength test results validated the structural safety and durability of the project. It also demonstrated that the materials and methods used were appropriate, ensuring the long-term performance of the concrete elements. This testing phase provided critical assurance to the project stakeholders that the constructed structure would be capable of bearing the designed loads without risk of failure.

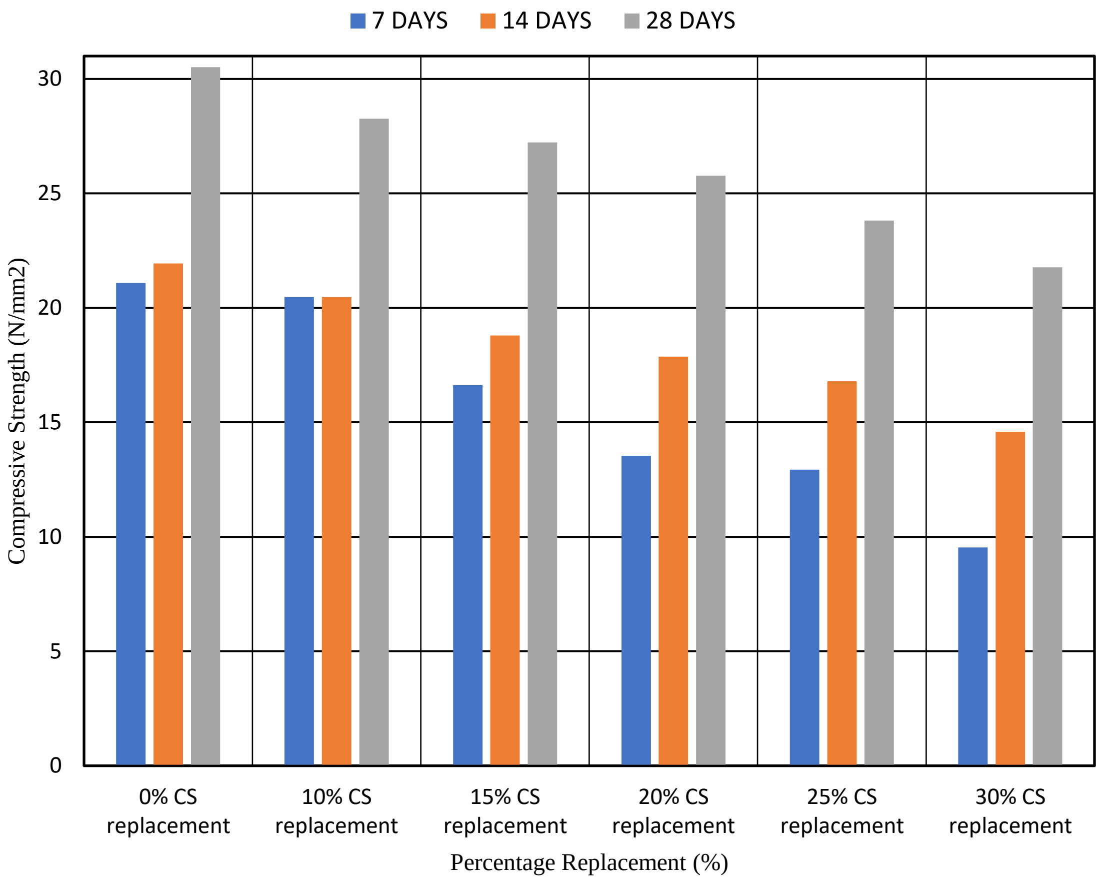

Figure 4.3: Comparative Chart Variation of Compressive Strength

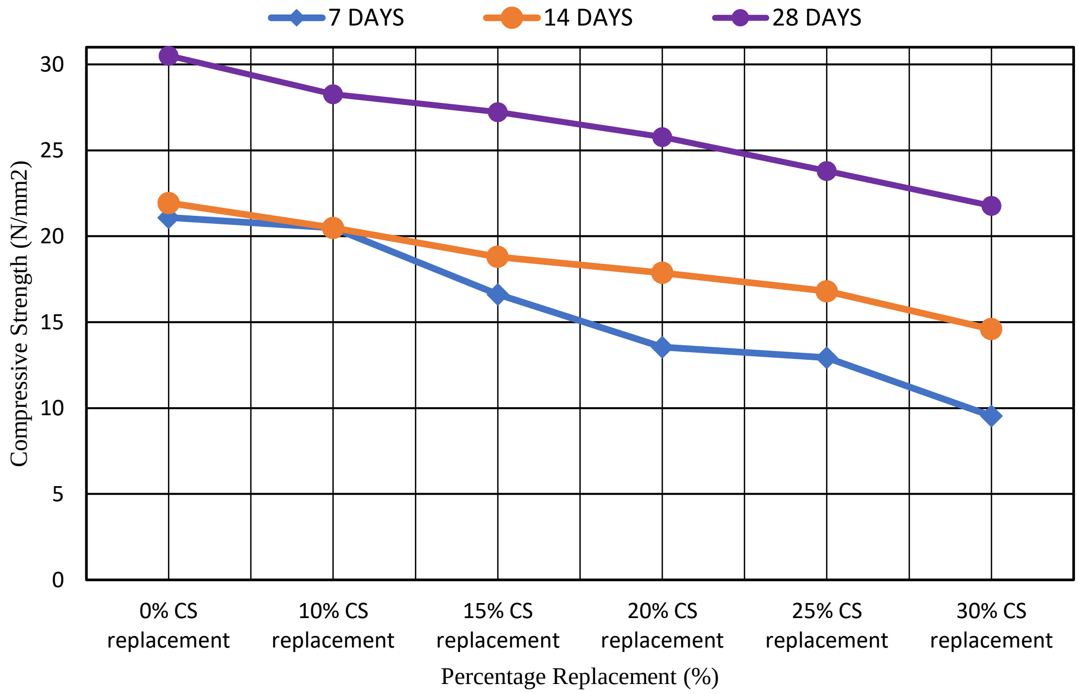

Figure 4.4: Comparative Graph of Compressive Strength

4.7 Splitting Tensile Strength Test

Table 4.7 below shows the results of the split tensile strength test at 7, 14, and 28 days

Table 4.7: Split tensile strength test results

% of replacement	**Average Compressive Strength**			**Split Tensile Strength**		
	7 days	14 days	28 days	7 days	14 days	28 days
0	21.09	23.90	30.51	2.30	2.41	2.50
10	20.48	20.48	28.27	2.13	2.23	2.36
15	16.62	18.80	27.23	2.06	2.15	2.22
20	13.54	17.87	25.78	2.03	2.10	2.18
25	12.93	16.80	23.81	1.92	2.00	2.08
30	9.54	14.59	21.77	1.88	1.95	2.03

The splitting tensile-strength test was conducted to assess the concrete's ability to resist tensile forces, which is crucial to ensuring the durability and crack resistance of structural elements. Since concrete is inherently weak in tension, this test helps evaluate its indirect tensile strength and the effectiveness of reinforcement in handling tensile stresses. To perform the test, cylindrical concrete specimens measuring 150 mm in diameter and 300 mm in height were prepared from the same batches used in construction. These samples were carefully cast and compacted to eliminate air voids, ensuring uniform density and consistency. After molding, the cylinders were cured for 7, 14, and 28 days to allow proper hydration and strength development. Once the curing periods were complete, the specimens were tested on a compression testing machine following standard procedures. Each cylinder was placed horizontally between two steel loading strips to ensure uniform force distribution. A gradual load was applied along the vertical diameter of the cylinder, inducing an indirect tensile stress in the concrete until it failed by splitting along its length. The successful completion of the splitting tensile strength test validated the quality of the concrete mix and the effectiveness of construction practices. It demonstrated that the concrete used in the project had adequate tensile resistance to support structural loads and minimize the risk of cracking under service conditions. This test provided confidence that the concrete elements would perform as expected, ensuring long-term stability and durability

4.8 Flexural Strength Test

The results of the flexural strength test at 7, 14, and 28 days are presented in the tables below:

Table 4.8: Flexural strength test at 7days

FLEXURAL STRENGTH (7 DAYS)								
Percentage of replacement	**Cube No. (kN)**			**Average Strength (kN)**	**Weight of Cube (kg)**			**Strength (N/mm^2) F_t=PL/bd^2**
	1	2	3		1	2	3	
0%(Control)	7.0	4.0	5.0	5.3	13.15	13.00	13.10	2.67
10%	6.8	4.5	4.0	5.1	13.10	13.10	13.15	2.58
15%	6.0	5.0	3.5	4.8	13.05	13.00	13.00	2.34
20%	5.0	4.0	4.8	4.6	13.05	13.10	13.00	2.25
25%	4.2	4.0	4.5	4.2	12.95	12.90	12.90	2.15
30%	3.0	3.5	2.8	3.10	12.80	12.90	12.95	1.56

Table 4.9: Flexural strength test at 14 days

FLEXURAL STRENGTH (14 DAYS)								
Percentage of replacement	**Cube No. (kN)**			**Average Strength (kN)**	**Weight of Cube (kg)**			**Strength (N/mm^2) F_t=PL/bd^2**
	1	2	3		1	2	3	
0%(Control)	6.5	9.5	8.0	8.0	13.10	13.00	13.10	4.00
10%	6.0	8.5	7.5	7.17	12.90	12.90	12.95	3.95
15%	5.8	8.0	7.0	6.93	12.85	12.80	12.75	3.80
20%	5.5	7.5	6.5	6.50	12.80	12.75	12.70	3.49
25%	5.0	7.0	6.0	6.00	12.75	12.70	12.65	3.15
30%	4.5	6.5	5.5	5.50	12.70	12.65	12.60	2.96

Table 4.10: Flexural strength test at 28 days

FLEXURAL STRENGTH (28 DAYS)								
Percentage of replacement	**Cube No. (kN)**			**Average Strength (kN)**	**Weight of Cube (kg)**			**Strength (N/mm^2) F_t=PL/bd^2**
	1	2	3		1	2	3	
0%(Control)	10.0	12.00	12.5	11.50	12.95	13.00	13.10	5.75
10%	9.0	11.0	11.5	10.17	12.90	12.95	12.90	5.25
15%	8.5	10.5	10.0	9.33	12.85	12.80	12.75	4.90
20%	10.0	8.0	9.0	9.0	12.75	12.80	12.70	4.50
25%	7.5	9.50	8.5	8.5	12.75	12.70	12.65	4.20
30%	8.0	9.0	7.0	8.0	12.70	12.65	12.60	3.90

The flexural strength test was conducted to evaluate the concrete’s ability to resist bending stresses, which is essential for ensuring the durability and load-bearing capacity of structural elements such as beams, slabs, and pavements. Since concrete is relatively weak in tension, this test helps assess its performance under bending loads, where tensile forces develop in the lower portion of the structure.

To carry out the test, rectangular concrete beam specimens measuring 100 mm × 100 mm × 500 mm were prepared from the same batches used in construction. These samples were carefully cast and compacted to eliminate air voids and ensure uniform density. After molding, the specimens were cured in water at 27°C for 7, 14, and 28 days to allow for proper hydration and strength development.

Once the curing periods were complete, the specimens were tested using a universal testing machine according to the standard third-point loading method. Each beam was supported at both ends, and a gradually increasing load was applied at two equidistant points along its span until failure occurred. The load at failure was recorded, and the flexural strength was calculated using the formula:

$$\mathbf{F = PL / (bd^2)}$$

Where F is the flexural strength, **P** is the maximum applied load, **L** is the span length, **b** is the width, and **d** is the depth.

The successful completion of the flexural strength test confirmed that the concrete mix used in the project was of high quality and that the construction practices were effective. It demonstrated that the concrete elements could withstand bending forces without excessive cracking or failure, ensuring the long-term stability and durability of the structure. This test provided confidence in the structural integrity of the project, particularly for components subjected to flexural stresses such as beams, pavements, and bridge decks.

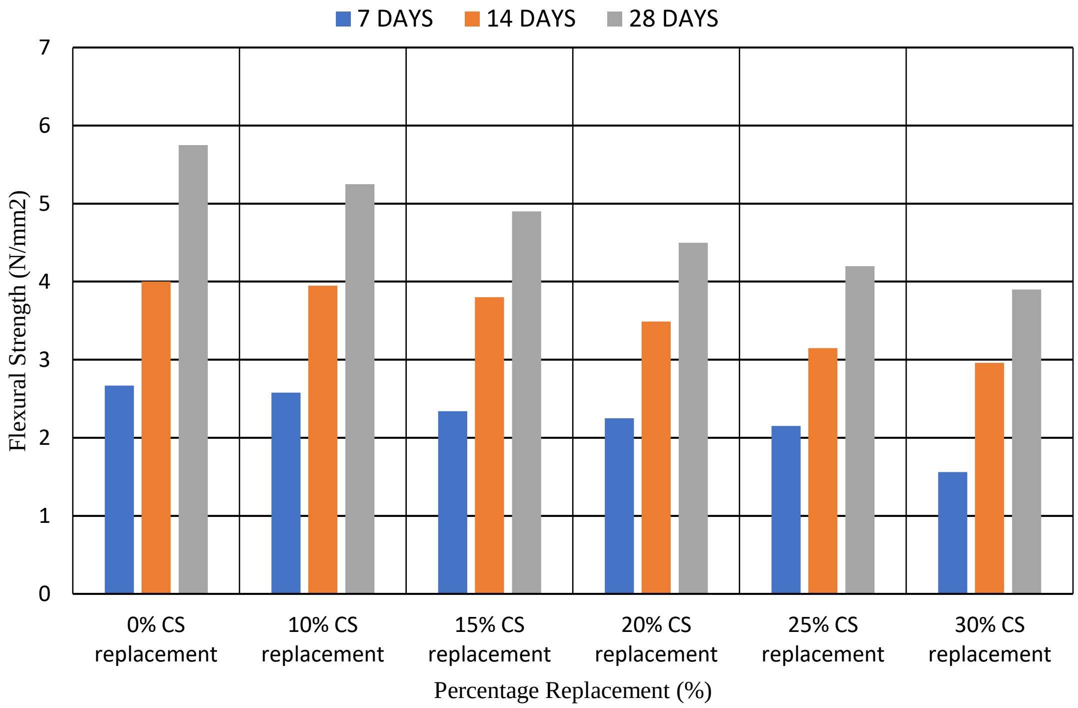

Figure 4.5: Comparative Chart Variation of Flexural Strength

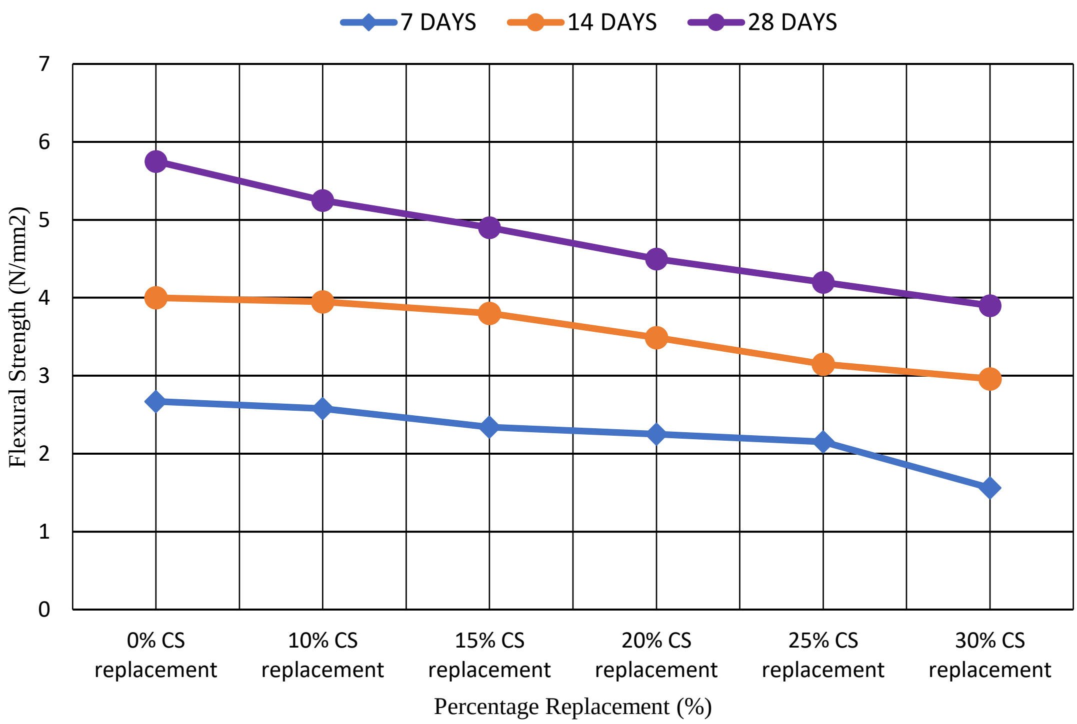

Figure 4.6: Comparative Graph Variation of flexural strength

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study investigated the feasibility of using crushed CS as a partial replacement for coarse aggregate in concrete, with replacement levels of 0%, 10%, 15%, 20%, 25%, and 30%. The experimental tests involved slump tests to assess workability and compressive, split tensile, and flexural strength tests at 7, 14, and 28 days of curing to evaluate the effects of incorporating coconut shells in concrete mixtures. The results demonstrated that coconut shells can be effectively used as a sustainable alternative to conventional aggregates, offering both environmental and economic benefits.

The sieve analysis confirmed that the coconut shell aggregates were well-graded and met the particle-size distribution requirements for use in concrete. The slump test results showed that workability decreased as the proportion of crushed CS increased, indicating that higher replacement levels require additional water or admixtures to maintain the desired consistency. However, at lower replacement levels, the slump values remained within acceptable limits, ensuring ease of placement and finishing.

Compressive strength tests revealed that concrete containing crushed CS exhibited a gradual decrease in strength with increasing replacement levels. At 10% replacement, the 7-day compressive strength was 16.72 N/mm^2, while the 28-day strength was 28.27 N/mm^2, compared with the control mix, which achieved an average compressive strength of 30.51 N/mm^2 at 28 days. These results indicate that moderate replacement levels can achieve acceptable strength for structural applications while contributing to sustainability.

Flexural strength tests showed a similar trend, with the highest flexural strengths recorded at lower replacement levels, confirming that coconut shells contribute to the structural integrity of concrete. Similarly, the flexural strength at 28 days decreased from 5.75 N/mm^2 in the control to 5.25 N/mm^2 for the 10% replacement mix. The splitting tensile strength test results indicated that the lowest tensile strength (0.83 N/mm^2) was observed at 30% replacement after 7 days, while the highest tensile strength (1.82 N/mm^2) was achieved at 10% replacement. This suggests that coconut shells can provide reasonable tensile strength, making them suitable for non-load-bearing, lightweight concrete applications.

Overall, the study concludes that crushed CS can be utilized as a partial replacement for coarse aggregates in concrete production. While higher replacement levels may reduce mechanical properties, a 10% replacement provides an optimal balance between strength, workability, and sustainability. The use of CS in concrete reduces waste, lowers reliance on natural aggregates, and supports eco-friendly construction practices.

5.2 Recommendations

Based on the findings of this research, the following recommendations are made:

1. Further Testing: Long-term performance evaluations, including durability tests such as water absorption, freeze-thaw resistance, and sulfate attack resistance, should be conducted to assess the lifespan of crushed CS-modified concrete.
2. Field Applications: Pilot-scale projects should be carried out to assess the practical implications of using crushed CS in real-world construction scenarios, especially in developing regions where material costs and sustainability are significant concerns.
3. Structural Applications: Further research should explore the potential of crushed CS-modified concrete for structural applications such as beams and columns to determine its feasibility in load-bearing elements

4. Recycling and Waste Management: Governments and construction firms should develop strategies to encourage the recycling of crushed CS, reducing environmental waste and promoting sustainable construction.

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APPENDIX

Figure A-1: Concrete mix before pouring into mould

Figure A-2: Weighing the concrete cubes

Figure A-3: Performing Flexural Test

Figure A-4: Performing Compressive Strength Test