EVALUATION OF PARTIAL REPLACEMENT OF COARSE AGGREGATE WITH PALM KERNEL SHELL IN GRADE 20 CONCRETE.

BY

AGHOLOR, Joy Nwakanma

ENG2002147

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

IN

THE DEPARTMENT OF STRUCTURAL ENGINEERING,
FACULTY OF ENGINEERING,
UNIVERSITY OF BENIN, BENIN CITY, NIGERIA

JULY, 2025.

PLAGIARISM

This work **EVALUATION OF PARTIAL REPLACEMENT OF COARSE AGGREGATE WITH PALM KERNEL SHELL IN GRADE 20 CONCRETE** by AGHOLOR, Joy Nwakanma
with Matric Number ENG2002147 of the department of Structural Engineering, Faculty of Engineering, University of Benin City, Edo State, Nigeria, has PASSED the PLAGIARISM TEST.

PROJECT COORDINATOR:

Name: Engr. I . O Abolagba

Signature and Date: ....

CERTIFICATION

This is to certify that this work was carried out by AGHOLOR, Joy Nwakanma, Mat. No. ENG2002147, of the Department of Structural Engineering, University of Benin City, Edo State, Nigeria.

SUPERVISOR:

Name: Prof. R.I. Umasabor

Signature and Date: …………………………………………….

HEAD OF DEPARTMENT:

Engr. Prof. R.I. Umasabor

Signature and Date: …………………………………………….

DEDICATION

I humbly dedicate this project to God Almighty who by his sure grace and profound mercy has granted me good health, wisdom, knowledge and understanding all through my stay in the University of Benin.

ACKNOWLEDGEMENT

First and foremost, my sincere gratitude goes to God Almighty for his immense grace, favor and protection upon my life from the beginning of my degree in the University of Benin.

I would also like to express my deepest gratitude to my project supervisor and Head of the Department of Structural Engineering, University of Benin, Engr. Prof. R.I. Umasabor for his guidance, support and expertise during my research. I would like to acknowledge my lecturers Engr. Prof. (Mrs.) N.I. Ihimekpen, Engr. Dr Iziengbe Inerhunwa, Engr. Prof. O.U Orie, Engr. Prof. S.O Osuji, Engr. Prof. A.N Aniekwu, Engr. Prof. H.A.P Audu, Engr. Prof. J.O Okovido, Engr. Prof. E. Nwankwo, Engr. Dr. R.O Ogirigbo, Engr. Dr. N. Kayode Ojo, Engr. Dr. A Rawlings, Engr. Dr. R Ilaboya, Engr. Dr. L.O Bobor, Engr.Dr. S.E Okunofua, Engr. Dr. P.N Ogbeifun, Engr. Dr. S.A Adegbemileke, Engr. U. Ukeme, Engr. E Oria-Usifo, Engr. E. Musa, Engr. O. Oriakhi, Engr. B. Omosefe, Engr. C. Okolie, Engr. O. Osasu, Engr. Ambrose Agabi, Engr. U.K Ogbonna, Engr. G.E Evbaru-Okhuahesuyi, Engr. J.O Odemerho, for laying a solid foundation of academic rigor and professionalism within the department. My sincere appreciation goes to all the lecturers and staff of the Department of Structural Engineering, University of Benin, for their academic support and mentorship during my project.

I remain very thankful to my parents, Engr. Lucky Agholor and Mrs Evelyn Agholor, and my siblings, Daniella, Naomi, Jaiden, Eliana and Bernice, for their prayers and support that greatly contributed to my success in my education.

I would like to acknowledge Mr Ayodele Jeremiah, Mr Ovbagbedia Ejiro, Mrs Uzamere Adesuwa and Engr, John. I am forever grateful for all their support and contributions. God bless you all. I also acknowledge my friends and colleagues for their companionship, intellectual discussions,

and moral support throughout this project.

ABSTRACT

Concrete is one of the most widely used construction materials in Nigeria due to its strength, durability, and versatility. However, the increasing cost of granite and the environmental impact of quarrying have created the need for alternative, sustainable materials. At the same time, palm kernel shell (PKS), a by-product of palm oil processing, is generated in large quantities and often disposed of as waste, leading to environmental pollution. This study investigates the suitability of palm kernel shell as a partial replacement for granite in Grade 20 concrete.

Granite was partially replaced with PKS at 0%, 10%, 20%, and 30% by weight. The physical properties of PKS, including specific gravity, bulk density, and aggregate impact value, were determined. Concrete mixes were produced and tested for workability using the slump test, as well as fresh and hardened density. Concrete cube specimens were cast and cured for 7, 14, and 28 days before compressive strength testing in accordance with relevant British Standards

The results indicated that the incorporation of PKS reduced the density of concrete, confirming its potential for lightweight applications. Workability and compressive strength decreased with increasing PKS content due to the high water absorption and lower strength of PKS compared to granite. However, concrete containing up to 20% PKS achieved compressive strength values close to the target strength for Grade 20 concrete at 28 days. It was concluded that palm kernel shell can be used as a partial replacement for granite up to an optimum level of 20%, offering a cost-effective and environmentally friendly alternative for sustainable concrete production.

TABLE OF CONTENT

LIST OF PLATES

ACRONYMS

PKS – Palm Kernel Shell

OPC – Ordinary Portland Cement **PKSA** – Palm Kernel Shell Ash **PCE** – Polycarboxylate Ether **SSD** – Saturated Surface Dry **AIV** – Aggregate Impact Value **BS** – British Standard

BSI – British Standards Institution

w/c – Water–Cement Ratio

w/b – Water–Binder Ratio

LC^3 – Limestone Calcined Clay Cement

EMC – Energetically Modified Cement

SCM – Supplementary Cementitious Material

MPa – Megapascal

kg/m^3 – Kilogram per Cubic Metre

g – Gram

mm – Millimetre

°C – Degrees Celsius

µm – Micrometre

UPV – Ultrasonic Pulse Velocity **B.Eng** – Bachelor of Engineering **CO$_2$** – Carbon Dioxide

CHAPTER ONE INTRODUCTION

1.1 BACKGROUND STUDY

Concrete is one of the most commonly used materials in construction, especially in developing countries like Nigeria, where it forms the foundation of most residential and public infrastructure. The major components of concrete—cement, water, fine aggregate, and coarse aggregate—play important roles in determining its overall performance and strength. Among these, coarse aggregate, which is usually granite, makes up a large portion of the concrete mix. However, the increasing demand for granite has led to a rise in cost and overdependence on quarrying, which negatively impacts the environment through land degradation, dust pollution, and the depletion of natural resources.

In recent years, there has been growing interest in using alternative materials to partially replace granite in concrete. One material that has shown potential is palm kernel shell (PKS), which is a by-product of palm oil production. In many parts of Nigeria and West Africa, PKS is discarded as waste and often left to pollute the environment. Rather than leaving these shells to accumulate in dumpsites or water bodies, they could be processed and used as a partial replacement for granite in concrete.

Several recent studies have explored this idea. Ohene-Coffie *et al*. (2024) investigated how using PKS in reinforced concrete affects bond strength and found it to be suitable for certain applications. Yiwo *et al*. (2023) looked at the use of untreated dura palm kernel shells in lightweight pervious concrete, showing good results in terms of drainage and weight reduction, which could help reduce urban flooding. Yusuf and Jimoh (2023) also used ultrasonic pulse velocity testing to assess how strong PKS concrete remained over time, particularly for roadworks, while Odeyemi *et al*. (2024) studied its performance in self-compacting concrete.

These studies suggest that palm kernel shell can reduce the cost and weight of concrete while contributing to better waste management and more sustainable construction practices. By evaluating how well PKS performs in a common concrete grade like Grade 20, which is widely used for light structural elements, this research could help promote a greener and more affordable approach to building in developing regions.

1.2 STATEMENT OF THE PROBLEM

In the Nigerian construction industry, concrete remains a foundational material due to its strength, versatility, and widespread availability. A key ingredient in concrete is coarse aggregate, which is typically derived from crushed granite. However, the increasing cost of granite has contributed to a significant rise in overall construction costs, posing challenges particularly for low-income earners and small-scale developers in rural and semi-urban areas where the demand for affordable housing and infrastructure is high (Yusuf and Jimoh, 2023).

Beyond economic implications, granite quarrying has considerable environmental drawbacks, including deforestation, habitat destruction, land degradation, dust pollution, and greenhouse gas emissions. These concerns underscore the urgent need to explore sustainable, cost-effective, and environmentally friendly alternatives to conventional aggregates.

At the same time, Nigeria's palm oil industry generates a large volume of palm kernel shells (PKS) as agricultural waste. Often disposed of by open dumping or burning, PKS contributes to environmental pollution and poses serious waste management challenges (Yiwo *et al.*, 2023). Recent studies have indicated that PKS may serve as a viable alternative material in concrete, particularly in lightweight or non-load-bearing applications. For instance, research by Yiwo *et al.* (2023), Ohene-Coffie *et al.* (2024), and Odeyemi *et al.* (2024) highlights its suitability in pervious, reinforced, and self-compacting concrete mixes.

Despite these promising results, several research gaps persist. Most prior investigations have focused on high-strength lightweight concrete or specialized applications, with limited empirical data on PKS use in Grade 20 concrete—a strength class widely used in walkways, slabs, and low- rise buildings. Furthermore, while individual studies have evaluated the physical or mechanical properties of PKS, few have systematically examined the combined effects of aggregate replacement levels, optimized grading, and controlled water–cement ratios.

Another critical issue is PKS's high absorption rate, which affects workability, water demand, and durability—especially under varying curing conditions. While polycarboxylate ether (PCE) superplasticizers have shown potential in improving workability, there remains a lack of in-depth studies on how PCE interacts with PKS to optimize strength and sustainability in normal-strength mixes like Grade 20 concrete.

Moreover, most studies have relied solely on destructive tests (e.g., compressive strength), while non-destructive techniques such as ultrasonic pulse velocity (UPV), which provide early indicators of structural integrity, have received limited attention. A combined testing protocol could offer a more comprehensive understanding of performance and support the development of reliable predictive models.

This study therefore aims to bridge these gaps by evaluating the effects of partially replacing granite with PKS at various levels (0%, 10%, 20%, and 30%) in Grade 20 concrete, while also examining the role of PCE superplasticizer, water–cement ratio, density, workability, compressive strength, and the applicability of both destructive and non-destructive testing methods. Ultimately, the goal is to assess the technical and economic viability of PKS as a sustainable aggregate in real- world concrete applications.

1.3 AIM AND OBJECTIVES

The primary aim of this study is to evaluate the effect of partially replacing granite with palm kernel shell on the properties of Grade 20 concrete.

The specific objectives of the study are to:

1. Determine the physical and mechanical properties of palm kernel shell relevant to its use as coarse aggregate.
2. Identify the optimal percentage of PKS that can be used to partially replace granite without significantly reducing concrete strength..
3. To determine the density of the PKS concrete at different various replacement levels.

1.4 SCOPE OF STUDY

This study is focused on assessing the suitability of palm kernel shell (PKS) as a partial replacement for granite in the production of Grade 20 concrete, which is commonly used for walkways, floors, and other non-load-bearing structures. The aim is to understand how PKS affects key properties such as workability, density, and compressive strength. This research is limited to the following tests on the normal and the palm kernel shell (PKS) concretes:

1. Sieve Analysis Test
2. Specific Gravity Test
3. Bulk Density Test
4. Slump Test
5. Density Test
6. Impact Value Test
7. Compressive Strength Test

1.5 JUSTIFICATION OF STUDY

The increasing demand for concrete in both residential and infrastructural development has led to the excessive exploitation of natural coarse aggregates like granite. This has contributed to rising construction costs and environmental degradation due to quarrying activities. In Nigeria and other tropical countries, granite is not only expensive but also not readily accessible in some regions, forcing contractors to source it from distant locations—further increasing cost and carbon emissions (Yusuf and Jimoh, 2023).

Meanwhile, palm kernel shells (PKS), which are by-products of palm oil processing, are generated in large quantities across the country. These shells are typically disposed of in open dumps or burnt, creating pollution and wasting a potentially valuable resource. Utilizing PKS as a partial replacement for granite offers a dual benefit: it helps reduce the reliance on non-renewable resources like granite and offers a sustainable way to manage agricultural waste (Yiwo *et al.*, 2023).

Recent studies have shown that PKS can be used in concrete without severely compromising strength, especially for applications where high-load bearing is not a critical requirement. For instance, research by (Ohene-Coffie *et al*. 2024) highlighted the ability of PKS to bond well in reinforced concrete applications. Similarly, (Odeyemi *et al*. 2024) noted that PKS concrete could achieve good flexural strength in self-compacting mixes. However, there is limited focus on its performance in Grade 20 concrete, which is one of the most widely used grades in low-rise buildings, walkways, and general-purpose construction.

This study is justified because it focuses on assessing the viability of a readily available, low-cost, and eco-friendly material (PKS) in place of granite in a common concrete grade. If successful, it could reduce construction costs, promote sustainability, and offer a useful solution for managing agro-industrial waste—especially in regions where palm oil production is high.

CHAPTER TWO LITERATURE REVIEW

2.1 CONCRETE

Concrete is a major component of most of our infrastructural facilities today in the 21st century because of its versatility in use. Concrete is used more than any other manmade material in the world. The importance of concrete in modern society cannot be underestimated according to NBRRI (2009), building failure occurs far more frequently during the construction period than in service. Unfortunately, this is the practice in Nigeria even though the construction industry had produced quite a reasonable quantity of trained and experienced professionals specialized in this area of training. The reasons these professionals are not being maximally utilized remain a paradox. (Adebobola *et al.*,2023)

The increasing demand for affordable and sustainable construction materials has driven research into alternative resources that can replace or supplement traditional concrete constituents. Concrete remains the most widely used construction material globally due to its durability, strength, and versatility. However, its production is heavily dependent on the continuous extraction of natural aggregates such as granite, which poses significant environmental and economic challenges (Danso and Appiah-Agyei, 2021).

In developing countries like Nigeria, where construction growth is rapid and natural resources are finite, the need for sustainable practices is particularly urgent. The depletion of granite resources leads not only to higher material costs but also to environmental degradation, including deforestation, loss of biodiversity, and increased carbon emissions associated with mining activities (Yusuf and Jimoh, 2023). Therefore, identifying suitable substitutes for granite in concrete production has become a key area of focus in sustainable construction research.

One promising alternative is the use of agricultural waste materials, particularly palm kernel shell (PKS), which is abundantly available in regions where palm oil production is a major industry. PKS is typically discarded as waste, contributing to environmental pollution and posing serious disposal problems (Fapohunda *et al.*, 2022). Its utilization in concrete not only offers a sustainable method for waste management but also provides a cost-effective solution for reducing the demand for natural aggregates.

Several researchers have investigated the feasibility of using PKS as a partial or full replacement for granite in concrete. These studies have explored its effects on various concrete properties such as workability, density, compressive strength, flexural strength, durability, and microstructure (Boateng *et al*., 2023; Kolo *et al*., 2022; Oriola *et al*., 2021). While many of these studies show promising results, most have been conducted on lightweight concrete or other specialized types of concrete, leaving a research gap in the area of normal strength concrete, particularly Grade 20 concrete, which is widely used in general construction applications such as walkways, floors, pavements, and non-load-bearing structures.

This chapter presents a comprehensive review of the literature related to the use of palm kernel shells in concrete. It covers the fundamental composition of concrete, previous related works, the physical and mechanical properties of PKS, and its impact on the performance of concrete. Furthermore, it identifies the existing research gaps that this study seeks to address by investigating the partial replacement of granite with PKS specifically in Grade 20 concrete.

2.2 CONSTITUENTS OF CONCRETE

2.2.1 Cement.

Cement plays a central role in concrete as the primary binding agent, and recent developments in sustainable construction have focused on reducing the carbon footprint of Ordinary Portland Cement (OPC) while maintaining its structural integrity. One notable approach involves replacing a portion of cement with Palm Kernel Shell Ash (PKSA), a by-product of the palm oil industry. According to Amartey *et al*. (2023), replacing 5-15% of OPC with PKSA resulted in improved compressive strength at later stages from about 27 MPa at 60 days to over 31 MPa at 90 days, highlighting both performance gains and environmental benefits.

In addition to PKSA, other alternatives like Limestone Calcined Clay Cement (LC^3) are gaining attention for their ability to reduce CO_2 emissions by up to 40% compared to conventional OPC. These materials are particularly suitable for regions such as sub-Saharan Africa and South Asia, where natural clay deposits are readily available (Scrivener *et al*., 2018).

The cement industry is also exploring more radical solutions, including zero-carbon cement technologies. Companies like Cemonite in Norway are developing mineral-based cements that avoid clinker altogether, while firms such as Sublime Systems and Brimstone are scaling production of low-emission binders using electrochemical processes and alternative raw materials (Reuters, 2023; Financial Times, 2024).

Another innovation is Energetically Modified Cement (EMC), which reduces energy consumption in production. A new EMC plant launched in Amsterdam in 2024 reportedly achieves up to one million tonnes of annual CO_2 savings by eliminating the traditional energy-intensive clinker phase (The Times, 2024).

Despite these advances, cement production still contributes nearly 8% of global carbon emissions. As such, using supplementary cementitious materials (SCMs), including fly ash, slag, calcined clay, and agricultural ashes like PKSA, remains one of the most practical strategies to curb emissions while maintaining performance and reducing costs.

This research builds on these sustainable trends by examining how partial replacement of OPC with PKSA can improve both the environmental footprint and compressive strength of Grade 20 concrete, offering a low-cost, eco-friendly alternative for everyday construction.

2.2.2 Water

Water is not merely a mixing medium in concrete but a vital component that initiates cement hydration and influences the formation of the hardened concrete microstructure. The water - cement (w/c) ratio, which denotes the mass of water relative to cement, remains the most critical factor in determining concrete strength, durability, and permeability. A lower w/c ratio typically results in a denser and stronger concrete matrix. However, such reductions can reduce workability unless chemical admixtures are employed.

Recent studies have reinforced the importance of an optimal w/c ratio. For instance, elevated w/c or water-binder (w/b) ratios (such as 0.46) have been shown to increase porosity and facilitate chloride ingress, significantly reducing compressive strength by over 50% under aggressive environmental conditions (Zhao *et al.*, 2024). Similarly, research on concrete incorporating manufactured sand reported a decrease in tensile strength by up to 15% when the w/c ratio was raised from 0.34 to 0.49, further highlighting the detrimental effects of excess water (Chen and Gao, 2023).

To maintain workability at low w/c ratios, superplasticizers particularly polycarboxylate ethers (PCEs) are essential. These high-range water reducers allow for w/c ratios as low as 0.20–0.38 without compromising the flow or strength of the mix, making them ideal for high-performance concretes such as self-compacting or lightweight concrete incorporating materials like palm kernel shell (PKS) (Tianjin University, 2024).

In specialty concretes such as foamed concrete, studies suggest that a w/c ratio around 0.50 strikes an optimal balance between fluidity and mechanical performance, especially when quality control techniques like ultrasonic testing are used to monitor uniformity and void content (Fapohunda *et al*., 2023).

Furthermore, proper water distribution during the curing phase is crucial but often overlooked. Adequate curing ensures continuous hydration, reduces shrinkage cracking, and enhances long-term durability. On the other hand, excessively high w/c ratios (e.g., >0.60) tend to cause segregation, bleeding, and surface inconsistencies, ultimately compromising both the aesthetics and structural integrity of the concrete (Neville and Brooks, 2010).

In summary, water management in concrete is a delicate balance. While necessary for hydration and workability, improper ratios can lead to inferior strength and durability. As such, controlling the w/c ratio, alongside the strategic use of admixtures and proper curing practices.is vital for producing high-quality, long-lasting concrete.

2.2.3 Aggregate Fine Aggregate

Natural river sand has traditionally been the preferred choice for fine aggregate in concrete due to its consistent grading, cleanliness, and ability to form dense, workable mixes. However, in response to growing environmental and economic concerns, recent research has explored the potential of using crushed palm kernel shell (PKS) as a partial replacement for fine aggregates.

Muomaife (2021) conducted a comparative sieve analysis of PKS and river sand, revealing that while sand exhibited a favorable grading coefficient of approximately 2.5, indicative of tight particle packing and low void content—PKS showed a coarser texture with a uniformity coefficient near 1.0. This lower grading efficiency led to higher void ratios and poorer mechanical performance unless PKS was blended with well-graded sand. These findings underscore the importance of careful aggregate preparation, especially in mixes seeking to maintain strength and workability.

Water absorption presents an additional challenge. A study by Usman *et al.* (2022) reported that fine PKS could absorb more than 20% of its own weight in water, compared to less than 2% for natural sand. This stark difference means that PKS, if used untreated, significantly increases the water demand of a concrete mix to maintain slump, thereby risking excessive shrinkage and increased porosity in the hardened material.

Research on similar agricultural waste materials, such as coconut shells, has found that partial substitution of fine aggregate, up to about 10%, can yield acceptable results, with only modest reductions in strength and density. However, beyond this threshold, workability deteriorates, and compressive strength drops markedly (Akinmusuru and Adamu, 2023).

Taken together, these studies suggest that while PKS can serve as a fine aggregate replacement, its use should be limited to around 10–20% for optimal results. Success depends heavily on strategies such as proper particle grading, potential pre-soaking to manage absorption, or mechanical processing to improve texture. Notably, concrete mixes with just 10% PKS replacement have achieved compressive strengths close to 27 MPa—comparable to conventional Grade 20 concrete—demonstrating that with thoughtful design, lightweight and structurally sound materials are attainable (Fapohunda *et al*., 2022).

Coarse Aggregate

Granite is widely regarded as the standard material for coarse aggregate in concrete due to its high density, abrasion resistance, and superior compressive strength. However, its continuous extraction raises significant environmental and economic concerns, particularly in regions with limited quarry access and high transportation costs. In response to these challenges, researchers have explored the use of palm kernel shell (PKS) as a sustainable, lightweight alternative to granite.

A 2023 study conducted in Indonesia by Sahputra *et al.* demonstrated that substituting granite with PKS at levels up to 25% resulted in only a modest decline in compressive strength. Specifically, a 25% PKS mix achieved a strength of approximately 360 kg/cm² (36 MPa), compared to 380 kg/cm² in full-granite concrete, indicating that moderate replacement can be structurally viable. In contrast, a project at the Federal University of Technology, Owerri, reported that 25% PKS replacement yielded lower compressive strengths ranging from 12.7 to 16.6 MPa, sufficient for certain non-load-bearing applications but highlighting a clear downward trend in strength as PKS content increased (Usman *et al*., 2022).

Further research by Olusola and Babafemi (2022) explored the influence of PKS particle size on concrete performance. Their results showed that larger PKS particles, approximately 20 mm in diameter, offered better strength outcomes at moderate replacement levels. For instance, 25% replacement with large-sized PKS achieved compressive strengths around 23 MPa, while 50% replacement still yielded 18 MPa, which is acceptable for lightweight structural applications.

Fapohunda *et al*. (2022) expanded on these findings by evaluating the microstructural implications of PKS in concrete. They observed that although the inclusion of PKS increased concrete porosity, a 10% PKS replacement mix maintained compressive strength and density levels comparable to conventional mixes (23 MPa at 28 days), especially when extended curing was applied to enhance hydration.

Overall, these studies suggest that PKS can effectively replace natural granite up to a certain threshold, typically around 25%, without severely compromising compressive strength. Optimizing PKS particle size and ensuring proper curing practices are essential to maintaining structural integrity. While higher PKS contents reduce mechanical performance, they may still be suitable for less demanding applications such as interlocking blocks, paving slabs, and other non- load-bearing structures.

2.2.4 Palm Kernel Shell (PKS): Characteristics and Engineering Potential

Palm kernel shell (PKS) is a by-product obtained from the mechanical cracking of palm nuts during palm oil extraction. It is a hard, fibrous, and irregularly shaped material, typically dark brown to black in color. With the rise of palm oil production in West Africa and Southeast Asia, large quantities of PKS are generated annually, often disposed of through open dumping or burning, posing environmental and public health risks (Fapohunda *et al*., 2022).

PKS is gaining attention in construction due to its lightweight nature, high carbon content, and abundance as an agro-industrial waste. Its physical properties, such as a bulk density ranging from 500 to 650 kg/m^3, water absorption typically above 20%, and relatively low crushing strength, make it unsuitable for high-load applications in raw form. However, when used in controlled percentages, PKS has proven effective as a partial replacement for coarse aggregate in lightweight or non-load-bearing concrete elements (Olusola and Babafemi, 2022).

PLATE 2.1

The use of PKS in concrete contributes to sustainability by:

1. Reducing dependence on quarried natural aggregates (e.g., granite),
2. Lowering concrete weight, which is beneficial in structures where dead load is a concern,
3. Enhancing waste management practices in palm-producing regions,
4. Potentially lowering the cost of construction materials.

However, PKS's high porosity and water absorption remain challenges. These traits can lead to increased water demand, reduced workability, and lower compressive strength if not properly accounted for. To mitigate these effects, strategies such as pre-soaking, particle size optimization, and the use of superplasticizers are commonly employed (Usman *et al*., 2022).

Furthermore, microstructural analysis of PKS-based concrete has revealed a more porous matrix, but one that still meets strength requirements for many general-use concrete applications when replacement levels are kept within the 10–30% range (Fapohunda *et al*., 2022).

2.2.4.1 Durability and Environmental Impact of Palm Kernel Shell as Coarse Aggregate in Grade 20 Concrete

Durability Considerations

The long-term performance and resistance of concrete to various environmental conditions define its durability. When palm kernel shell (PKS) is introduced as a partial or complete replacement for conventional coarse aggregates such as granite, several changes in durability-related properties emerge.

PKS is an organic, porous, and lightweight material derived from oil palm fruit waste. Its porous structure contributes to increased water absorption, often above 20% by weight, which may raise concerns about moisture retention and susceptibility to freeze-thaw cycles in temperate climates (Usman *et al*., 2022). However, in tropical countries like Nigeria, where freeze-thaw is not a dominant factor, the main concerns are related to permeability, shrinkage, and long-term strength loss due to microcracking.

Studies have shown that concrete mixes incorporating PKS at low to moderate replacement levels (10-25%) exhibit acceptable durability characteristics when proper mix design is employed. For instance, Olusola and Babafemi (2022) observed that 25% PKS replacement in Grade 20 concrete resulted in slightly increased porosity, yet 28-day compressive strengths remained within acceptable structural limits (23 MPa). Prolonged curing, typically 28 days or more, can mitigate the initial porosity effect, as water within the PKS structure gradually contributes to internal curing and improved hydration (Fapohunda *et al*., 2022).

Moreover, despite its relatively high water absorption, the inert chemical nature of PKS means it does not chemically degrade or leach into the concrete matrix. This contributes positively to the overall chemical stability of PKS-based concrete. In chloride-rich or mildly acidic environments, PKS concrete has demonstrated adequate resistance, though slightly reduced compared to granite concrete. The application of water-reducing admixtures (e.g., polycarboxylate ethers) and surface sealants further enhances durability.

Additionally, microstructure analysis using Scanning Electron Microscopy (SEM) has revealed that the interface transition zone (ITZ) between PKS and the cement paste is somewhat weaker than that of granite aggregates. This is primarily due to the rougher and more porous texture of PKS. Nevertheless, optimized grading, proper compaction, and extended curing help improve bonding and reduce long-term deterioration risks (Boateng *et al*., 2023).

In conclusion, while PKS does not completely match granite's performance in terms of durability, with appropriate design measures—such as limiting replacement to 30%, using admixtures, and ensuring adequate curing—it can produce Grade 20 concrete with sufficient service life for non- critical structural applications like walkways, driveways, and low-rise building components.

2.2.4.2 Environmental Impact

The use of PKS in concrete has significant positive environmental implications, particularly in regions where palm oil production is a major agricultural industry. As a by-product of palm oil extraction, PKS is often discarded in large quantities, contributing to waste accumulation, open burning, and landfill usage. Repurposing PKS into concrete not only addresses waste disposal issues but also reduces the demand for natural aggregates such as granite, whose extraction is energy-intensive and environmentally damaging.

Granite quarrying contributes to deforestation, dust pollution, noise, and ecosystem disruption. In contrast, PKS is a renewable agricultural waste product. Incorporating it into concrete helps conserve non-renewable resources and aligns with principles of sustainable construction. Life-cycle assessments (LCAs) have consistently shown that using agricultural residues like PKS can lower a concrete mix's carbon footprint by 10–25% depending on the substitution level and transportation distances (Yusuf and Jimoh, 2023).

Furthermore, the lightweight nature of PKS leads to a reduction in the overall mass of concrete, which can lower transportation energy and structural loads. In precast applications, this can result in lighter components, faster installation, and decreased structural foundation requirements, factors that indirectly reduce environmental impact.

Another environmental benefit lies in the reduction of embodied energy. Processing PKS (e.g., cleaning, grading) consumes significantly less energy compared to crushing and grading granite.

Thus, concrete containing PKS supports the development of low-carbon building materials, a growing priority in climate-resilient infrastructure.

Lastly, the integration of PKS supports circular economy principles, where agricultural by-products are reintegrated into new value chains rather than becoming pollutants. This enhances community livelihoods, promotes green job creation, and reduces the reliance on imported construction materials.

Palm kernel shell, when used as a partial replacement for coarse aggregate in Grade 20 concrete, offers a viable path toward more sustainable construction. While durability can be slightly compromised due to its porosity, careful mix design, limited replacement ratios, proper curing, and admixture use can ensure acceptable performance. Environmentally, PKS contributes to waste reduction, resource conservation, and reduced carbon emissions—making it a promising material in eco-friendly concrete production.

2.2.5 Admixtures

Admixtures play a vital role in modern concrete production by enhancing workability, controlling water content, and improving both fresh and hardened concrete properties. Among these, superplasticizers, particularly polycarboxylate ethers (PCEs), are widely recognized for their superior performance compared to older admixture types. A 2023 comparative study confirmed that PCEs significantly improve the flowability and slump retention of concrete for extended periods, even at low water-cement ratios, while allowing for reduced water demand without sacrificing strength (Ajol.info; Wiley Online Library; ScienceDirect, 2023). Researchers at Tianjin University (2024) further investigated various PCE formulations and found that certain structures dramatically lowered viscosity and improved fluidity in mixes with water-cement ratios as low as 0.30, enabling the development of high-strength, low-carbon concrete (Wiley Online Library, 2024).

In parallel, manufactured mineral additives such as palm kernel shell ash (PKSA) have attracted attention for their dual environmental and mechanical benefits. Amartey *et al.* (2023) demonstrated that replacing up to 15% of cement with PKSA increased compressive strength from approximately 27 MPa at 60 days to over 31 MPa at 90 days, while maintaining durability (FUDMA Journal of Science, 2023; Journal of Engineering Research and Reports, 2023). Similar findings were reported in self-compacting concrete, where 10–20% PKSA replacement maintained workability and met Grade 20 strength requirements (Wiley Online Library, 2023; ResearchGate, 2023).

When incorporating alternative aggregates like palm kernel shell (PKS), PCEs become even more important due to the high water absorption of PKS, which often exceeds 20% of its own weight. This increased absorption typically demands additional water to achieve workable mixes, which can compromise strength and durability. PCE superplasticizers counteract this issue by reducing the amount of free water needed while preserving workability, thus maintaining both strength and durability. This complementary relationship has been highlighted in recent studies (Tianjin University, 2024; Amartey *et al.*, 2023), demonstrating that PCE-enhanced PKS concrete can achieve acceptable slump values and compressive strengths suitable for structural applications. Although PKS and PCE do not directly interact chemically, their combined use addresses the specific workability challenges posed by lightweight, porous aggregates like PKS. Together, they offer a viable pathway for developing sustainable, structurally reliable concrete mixes that align with both environmental goals and engineering standards.

2.3 PREVIOUS RELATED WORKS

Numerous studies have explored the incorporation of PKS into concrete as a partial substitute for conventional aggregates, though with varying focus depending on application type. Olusola and Babafemi (2022) investigated PKS replacement levels and sizes, revealing that 25% coarse aggregate replacement using 20 mm PKS achieved compressive strengths close to 23 MPa, while 50% replacement still reached 18 MPa, adequate for lightweight concrete applications. Ifeanyi *et al.* (2023) confirmed that up to 25% PKS substitution resulted in compressive strengths compatible with general structural use, emphasizing PKS's viability for Grade 20 concrete.

Further hybrid studies have also been conducted. Osamuyi *et al.* (2021) examined combined use of PKS and periwinkle shells as complete aggregate replacements, noting compressive strengths around 50% lower than granite concrete but still adequate for non-structural, cost-effective applications. Kolo *et al.* (2022) developed predictive models that accurately forecasted slump and compressive strength for mixes containing up to 25% PKS, highlighting the value of predictive mix design in PKS-modified concrete.

Investigations by Fapohunda *et al*. (2022) into lateritic concrete with PKS up to 50% coarse aggregate replacement showed that while workability and strength declined at higher replacement levels, 10% substitution maintained comparable performance to conventional mixes. Extended curing periods were found to mitigate porosity effects. Yiwo *et al*. (2023) assessed untreated dura- type PKS in lightweight pervious concrete, identifying 25% replacement as optimal for balancing permeability and strength, with higher levels diminishing mechanical properties.

These findings collectively suggest that partial PKS substitution up to 25%, with careful grading, water management, and extended curing, can yield concrete meeting the requirements of Grade 20 applications. Building on this foundation, the present study will assess PKS replacements at 0%, 10%, 20%, and 30% for Grade 20 concrete, systematically evaluating workability, density, and compressive strength to optimize environmental sustainability alongside structural performance.

CHAPTER THREE METHODOLOGY

3.1 MATERIALS AND REAGENTS

The following materials were used in this study:

3.1.1 Material Sourcing (Conforming to British Standards)

All materials used in this study were locally sourced within Benin City, Edo State, Nigeria. Care was taken to ensure that each material conformed to relevant British Standards to guarantee quality, consistency, and reliability in line with standard concrete practices.

1. Cement

   The cement used was Ordinary Portland Cement (OPC), purchased from a recognized dealer around Uselu, Benin City. It was stored properly to prevent moisture exposure and lump formation. This cement type was chosen because it is widely accepted for general construction and met the quality criteria set out in BS EN 197-1:2011, which defines the composition and performance requirements of common cements.
2. Fine Aggregate (Sand)

   The fine aggregate was sharp river sand obtained from the Ogba River area. It was clean, free from clay, silt, organic matter, and other impurities. Sand was sieved to confirm compliance with the required grading for fine aggregates as outlined in BS 882:1992 and BS EN 12620:2013. The sand was used in its natural state without washing, as preliminary inspection showed it was clean and well-graded.
3. Coarse Aggregate (Granite)

   Crushed granite, sourced from a local quarry in Okhoro, Benin City, was used as the conventional coarse aggregate. It was angular in shape, properly graded, and free from loose dust and organic contaminants. The granite was within the 20 mm maximum size range and complied with specifications in BS EN 12620:2013, which governs aggregates for concrete applications.
4. Palm Kernel Shell (PKS)

   The palm kernel shells used in this study were collected from two sources: some were picked up directly from Uselu Market where they are usually discarded by palm oil sellers, while others were sourced from home-based palm oil processing activities. The shells were sorted, cleaned, and sun-dried to remove any remaining pulp or oil content. To ensure consistency in particle size, the shells were manually crushed to achieve a maximum size similar to the granite (20 mm). Preliminary tests, including water absorption, bulk density, and specific gravity, were conducted following the procedures in BS 812-2:1995 and BS 812-110:1990.

5. Water

   Clean, drinkable water from the public supply was used throughout the project, both for mixing and curing. No visible impurities or odor were observed. The water met the basic requirements set by BS EN 1008:2002, which covers the suitability of water for concrete mixing.

3.1.2 Material Testing

To ensure the quality, suitability, and consistency of all materials used in this research, a series of standard laboratory tests were conducted. These tests were carried out at the Civil Engineering Materials Laboratory using approved methods that conform to relevant British Standards. Each test focused on specific physical or mechanical properties critical to concrete performance, particularly when incorporating palm kernel shell as partial coarse aggregate.

1. Sieve Analysis Test

This test was carried out to determine the particle size distribution of the aggregates, both granite and crushed PKS. A stack of standard sieves ranging from 20 mm down to 75 µm was used, and samples were passed through the sieve assembly using a mechanical shaker. The percentage retained on each sieve was recorded to plot the grading curve. For PKS, special attention was paid to ensure its crushed size fit within the acceptable range for coarse aggregate, in line with BS 812- 103.1:1985 and BS EN 933-1:2012.

2. Specific Gravity Test

The specific gravity of both granite and PKS was determined using the water displacement method as described in BS 812-2:1995. The results provided insight into the density and weight characteristics of the aggregates. PKS, being a lightweight material, was expected to have a lower specific gravity than granite. This influenced the mix design and volume calculations.

3. Bulk Density Test

Bulk density was tested to evaluate the mass of aggregate per unit volume, including the voids between particles. The test involved filling a cylindrical container of known volume with the aggregate, tapping it gently, and weighing it. The bulk density of PKS was considerably lower than that of granite, consistent with findings from earlier research. The procedure followed BS EN 1097-3:1998.

4. Aggregate Impact Value (AIV) Test

The impact value test measures the toughness of coarse aggregate by determining its resistance to sudden shock or impact. Using an impact testing machine, 14 mm-10 mm sized samples of granite and PKS were subjected to repeated blows. The amount of crushed material passing through a 2.36 mm sieve was measured. This value indicates the material's strength under dynamic loads and was done according to BS 812-112:1990.

5. Slump Test

The slump test was conducted to assess the workability of the fresh concrete mix. It followed the procedure in BS EN 12350-2:2009. Fresh concrete was placed in a cone-shaped mold, which was lifted vertically, and the slump (subsidence) was measured. This test was crucial especially for mixes containing PKS due to its influence on workability.

6. Fresh and Hardened Density Test

Concrete density was measured both in the fresh and hardened states to evaluate how the inclusion of PKS affected the mass-to-volume ratio. This test was necessary because lighter aggregates like PKS could significantly reduce the density, influencing structural applications. Procedures followed BS EN 12390-7:2009 for hardened concrete.

7. Compressive Strength Test

Concrete cube specimens (100 mm × 100 mm × 10 mm) were cast and cured for 7, 14, and 28 days. They were tested using a universal testing machine to determine the compressive strength at different curing intervals. This was the most critical test for evaluating how PKS affected the load- bearing capacity of Grade 20 concrete. Testing followed BS EN 12390-3:2009.

3.2 SIEVE ANALYSIS AND GRADING OF AGGREGATE

Sieve analysis is a fundamental laboratory test conducted to determine the particle size distribution of aggregates. This test is essential in assessing whether an aggregate is well-graded, uniformly graded, or poorly graded, as these factors directly influence the workability, strength, and durability of concrete.

In this study, sieve analysis was performed on both the natural granite and the palm kernel shell (PKS) aggregates to confirm their suitability for use in concrete, in accordance with BS 812-103.1:1985.

Objective

The aim of the sieve analysis was to:

a. Identify the range of particle sizes present in each aggregate type.
b. Determine whether the aggregates fall within acceptable grading limits.
c. Establish the particle size distribution curve for comparison.
d. Aid in the proper design of concrete mix by ensuring the correct proportion of coarse and fine particles.

3.2.1 Equipment and Materials Used

a. A set of British Standard test sieves (20 mm, 14 mm, 10 mm, 5 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, and 75 µm)
b. Weighing balance (accurate to 0.1 g)
c. Mechanical sieve shaker
d. Drying oven
e. Brush and pan
f. Aggregate sample (granite and PKS)

3.2.2 Test Procedure

1. A representative sample of each aggregate (granite and PKS) was obtained using the quartering method. This ensures the sample used is uniform and not biased toward any particular particle size.
2. The aggregate samples were placed in an oven and dried at a temperature of approximately 105°C for 24 hours to remove all moisture. Drying is essential to prevent clumping and to ensure accurate measurement of particle sizes.
3. Once cooled, approximately 1000 grams of the dried aggregate was weighed using a digital weighing balance. This served as the initial weight before sieving.

4. The sieves were stacked vertically in descending order, starting from the largest opening (top) to the smallest (bottom). A pan was placed underneath the smallest sieve to collect the finest particles.
5. The weighed sample was poured into the top sieve, and the entire stack was placed into a mechanical sieve shaker. The machine was operated for a period of 10 to 15 minutes to ensure complete separation of particles.
6. After sieving, each sieve was removed and the material retained on it was collected and weighed separately. A clean brush was used to gently remove all particles from each sieve before weighing to prevent loss of fine material.
7. The mass of aggregate retained on each sieve was recorded. Though the results are presented in Chapter Four, the retained weights were later used to calculate the percentage retained and percentage passing through each sieve.
8. The sieves and equipment were cleaned after the test. The procedure was repeated for the other aggregate (either granite or PKS) to ensure consistency and proper comparison.

The sieve analysis gave valuable insight into the grading characteristics of both granite and PKS. Since PKS is a natural waste material with irregular shapes, its gradation needed to be carefully assessed to determine how well it could blend with granite in concrete without compromising performance.

3.3 SPECIFIC GRAVITY TEST

The specific gravity test was carried out to determine the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. This property is crucial in mix design calculations and helps to assess the suitability of the material for concrete production. In this study, the specific gravity of both granite and palm kernel shell (PKS) was determined using the pycnometer method for aggregates smaller than 10 mm, in accordance with BS 812-2:1995.

3.3.1 Apparatus Used

a. Pycnometer bottle (1-liter capacity)

b. Weighing balance (accurate to 0.1 g)

c. Oven (capable of heating to 105°C)

d. Desiccator

e. Dry clean cloth

f. Distilled water

g. Scoop or trowel

h. Aggregate sample (granite and PKS)

3.3.2 Test Procedure

1. A representative sample of each aggregate type (granite and PKS) was obtained and oven- dried at 105°C for 24 hours to remove all moisture. After drying, the sample was cooled to room temperature in a desiccator to avoid moisture absorption from the air.
2. About 200 to 300 grams of the dry aggregate was weighed and recorded as W_1 using a digital weighing balance.
3. The weighed aggregate was placed in a clean, dry pycnometer. Distilled water was added until the aggregate was fully immersed, and then the container was filled to the calibration mark. Air bubbles were eliminated by gently shaking or tapping the bottle.
4. The pycnometer containing both aggregate and water was weighed and recorded as W_2.
5. The aggregate was removed, and the pycnometer was cleaned, refilled with only distilled water up to the calibration mark, and weighed again. This was recorded as W_3.
6. Using the measured values, the specific gravity was calculated using the formula:

$$\text{Specific Gravity} = \left(\frac{W_1}{W_1 + W_3 - W_2}\right)$$

This value reflects the relative density of the aggregate in comparison to water. It is especially important when using PKS, as it is lighter than conventional aggregates like granite.

7. The test was repeated at least twice for each material (granite and PKS) to ensure accuracy and consistency in the values obtained.

This test was particularly useful in highlighting the lightweight nature of palm kernel shell when compared with traditional granite aggregate. The lower specific gravity of PKS is indicative of its porous and organic nature, which affects mix proportions and concrete performance.

3.4 BULK DENSITY TEST

The bulk density test is used to determine the mass of aggregate that occupies a unit volume, including the voids between particles. It plays a key role in concrete mix design because it influences the amount of aggregate required for a specific volume of concrete. In this research, the bulk density of granite and palm kernel shell (PKS) was determined to better understand how PKS affects the unit weight of concrete when used as a partial replacement for coarse aggregate. The procedure followed the guidelines in BS EN 1097-3:1998.

3.4.1 Apparatus Used

- A cylindrical metal container (of known volume, usually 5L or 15L)
- A straight steel tamping rod (16 mm diameter, 600 mm length)
- A weighing balance (sensitive to 0.1 g)
- Trowel or scoop
- Dry clean cloth
- Steel rule or flat edge
- Aggregate samples (granite and PKS)

3.4.2 Test Procedure

1. The coarse aggregate samples (granite and PKS) were oven-dried at 105°C for 24 hours to remove moisture, then allowed to cool in a desiccator. A representative portion was taken from the dry sample for the test.
2. The internal volume of the metal container was confirmed by filling it with water and measuring the weight of the water (since 1 litre of water = 1 kg), or by referring to the manufacturer's specified volume.
3. The container was filled in three layers. After pouring each layer of the aggregate, it was compacted using 25 strokes of the tamping rod. The top surface was leveled off with a steel rule or flat edge to ensure a flush and even surface. The filled container was then weighed, and the mass was recorded.
4. For the loose density, the container was filled without any compaction - simply by gently pouring the aggregate into the container until full. Again, the surface was leveled, and the weight recorded.
5. The bulk density was calculated using the formula: $\left(\frac{Mass\ of\ Aggregate\ in\ Container(kg)}{Volume\ of\ Container\ (m3)}\right)$

Both compacted and loose bulk densities were calculated separately to reflect how the material behaves in practical applications.

6. The bulk density of PKS was significantly lower than that of granite, which was expected due to its lower specific gravity and more porous structure. These values were later used in concrete mix proportioning and for evaluating how much weight reduction PKS contributes to the final concrete product.

3.5 AGGREGATE IMPACT VALUE (AIV) TEST

The Aggregate Impact Value (AIV) test was conducted to assess the toughness of the coarse aggregates - specifically, palm kernel shell (PKS) and natural granite - by measuring their resistance to sudden impact or shock. This test is particularly relevant for evaluating the suitability of aggregates in environments subjected to dynamic or repetitive loading, such as road surfaces, walkways, or structural components exposed to vibrations. The procedure followed is in accordance with BS 812-112:1990.

Purpose of the Test

The AIV test provides an indication of the aggregate's ability to withstand impact forces without breaking down. Aggregates with lower impact values are generally considered tougher and more desirable for structural concrete, while higher values suggest a higher tendency toward fragmentation under stress.

3.5.1 Apparatus Used

a. Aggregate Impact Testing Machine
b. Cylindrical steel cup and hammer (as specified in BS 812)
c. IS sieves (14 mm and 10 mm)
d. A balance (sensitive to 0.1 g)
e. Measuring cylinder
f. Tamping rod
g. Oven (capable of maintaining 105°C ± 5°C)

h. Steel straightedge

i. Tray and scoop

3.5.2 Test Procedure

1. Coarse aggregate samples were first washed and oven-dried at a temperature of 105°C for at least four hours to remove all moisture. The samples were then allowed to cool at room temperature.
2. The dried aggregates were sieved to collect particles passing through a 14 mm sieve but retained on a 10 mm sieve. This size range was selected as specified for the AIV test.
3. A cylindrical measure was filled with the sieved aggregate in three layers. Each layer was tamped 25 times using the standard tamping rod to ensure compaction and uniform density.
4. The filled mould was weighed to determine the initial mass of the test sample (W_1).
5. The mould containing the aggregate was then fixed in place in the impact testing machine. A standard hammer weighing 13.5-14.0 kg was raised to a height of 380 ± 5 mm and allowed to fall freely onto the sample 15 times. The repeated impacts caused the sample to break down into finer particles.
6. After impact, the contents of the mould were carefully removed and passed through a 2.36 mm sieve. The material retained on the sieve was discarded, and the amount passing through was collected.
7. The weight of the material that passed through the 2.36 mm sieve was measured and recorded as W_2.
8. The AIV was calculated using the formula: $\left(\frac{W_2}{W_1} \times 100\right)$

   where:

- W1 = original weight of sample before impact (g)
- W2 = weight of fines passing the 2.36 mm sieve (g)

Interpretation:

According to BS 812, an AIV less than 25% indicates a strong aggregate suitable for use in wearing surfaces like pavement layers, while values above 30% may suggest the material is too weak for structural concrete. In this study, this test served to compare the impact resistance of PKS to granite and assess whether PKS is suitable as a partial replacement for granite in Grade 20 concrete.

3.6 SLUMP TEST

The slump test was carried out to determine the workability and consistency of fresh concrete mixes incorporating palm kernel shell (PKS) as partial replacement for coarse aggregate. This test is crucial in understanding how easy the concrete is to mix, place, compact, and finish. It is especially relevant in this study, given the high water absorption rate of PKS, which can affect the fluidity of the mix.

The method adopted for the slump test follows the standard procedures outlined in BS EN 12350- 2:2009, which is the recommended code of practice for determining the consistency of fresh concrete using the slump cone method.

Purpose of the Test

Workability in concrete refers to the ease with which a mix can be handled and placed without segregation or bleeding. The slump test provides a quick and straightforward indication of this property. By observing how concrete behaves when the slump cone is lifted, one can judge if the mix is stiff, workable, or overly wet.

3.6.1 Apparatus Used

a. A standard slump cone (also known as Abrams cone): 300 mm high, 200 mm diameter at the base, and 100 mm at the top

b. Non-porous base plate (metal or plastic)

c. Tamping rod: 16 mm in diameter and 600 mm long with a hemispherical end

d. Trowel

e. Measuring scale or ruler

f. Tray and scoop
g. Stopwatch (for timing when needed)

3.6.2 Test Procedure

1. The concrete was freshly mixed with varying PKS replacement levels (0%, 10%, 20%, and 30%) and a constant water–cement ratio. Mixing was done manually on a clean, non- absorbent surface until a uniform, workable consistency was achieved.
2. The slump cone and base plate were cleaned, dried, and positioned on a flat, level surface. The interior of the cone was lightly moistened before use to prevent adhesion.
3. The cone was filled in three equal layers. Each layer was tamped 25 times using the tamping rod, with care taken to distribute the strokes evenly across the cross-section. Tamping ensured that each layer was compacted uniformly to reduce trapped air.
4. After filling the cone to the top, the excess concrete was struck off with a straight edge or trowel to make it level with the top of the mould.
5. The cone was then carefully and vertically lifted upward, without any rotational or lateral movement, in a steady motion over a period of 5 to 10 seconds.
6. The difference in height between the top of the mould and the highest point of the slumped concrete was measured using a ruler. This value, expressed in millimetres, was recorded as the slump.
7. Depending on the water content and PKS content of each mix, different types of slumps were observed - true slump (a uniform subsidence), shear slump (concrete slides sideways), or collapse slump (excessive water content). Only true slumps were considered valid in accordance with BS guidelines.

Relevance to the Study

Since PKS has a much higher water absorption capacity compared to natural granite, its inclusion in the concrete mix was expected to affect the slump values. The slump test was therefore a critical check to ensure the mixes remained workable without excess water, especially at higher replacement levels. Adjustments such as the use of polycarboxylate ether (PCE) superplasticizers were also noted where applicable to achieve desired consistency.

3.7 FRESH AND HARDENED DENSITY TEST

The density of concrete is an essential parameter in evaluating both its structural performance and material composition. In this study, the density of concrete was determined in two distinct states: fresh and hardened. Measuring the fresh density helps assess the uniformity and compactness of the concrete mix before setting, while hardened density gives insight into the material's durability and strength characteristics after curing. Both tests are especially important in this research because of the inclusion of palm kernel shell (PKS) as a lightweight aggregate, which can significantly influence the overall density of the concrete.

Objective of the Test

The primary goal of this test was to determine the unit weight of the concrete mixes at different stages, freshly mixed and fully cured, and to examine how increasing percentages of PKS affect the density of the concrete. A drop in density may suggest reduced structural strength or suitability for lightweight applications.

Standards Followed

1. Fresh density: BS EN 12350-6:2009 – Testing fresh concrete. Density.
2. Hardened density: BS EN 12390-7:2009 – Testing hardened concrete. Density of hardened concrete.

A. Fresh Density Test Apparatus Used

1. Rigid container of known volume (typically 7-10 litres)
2. Balance (accurate to ±10 grams)
3. Scoop and trowel
4. Measuring tape or ruler
5. Freshly mixed concrete sample

Test Procedure

1. The container was cleaned, dried, and weighed to obtain its empty weight.
2. Freshly mixed concrete was filled into the container in two to three layers. Each layer was tamped gently using a tamping rod or compacted using light vibration to eliminate trapped air without causing segregation.
3. The top surface was leveled using a trowel to ensure it was flush with the rim of the container.
4. The container filled with fresh concrete was then weighed.
5. The fresh density was calculated using the formula: $\left(\frac{Mass\ of\ full\ container - Mass\ of\ empty\ container}{volume\ of\ container\ (m^3)}\right)$

This test was repeated for each mix with 0%, 10%, 20%, and 30% PKS replacements.

B. Hardened Density Test Apparatus Used

1. Cured concrete cube specimens (100 mm × 100 mm × 100 mm)
2. Electronic weighing scale
3. Water tank for saturated surface-dry condition (optional for bulk or apparent density)
4. Vernier caliper or steel rule for volume measurement

Test Procedure

1. After 28 days of curing, the cube specimens were removed from water and allowed to reach saturated surface-dry (SSD) condition.
2. Each cube was weighed using a digital balance to record its mass.
3. The volume of each cube was calculated based on its measured dimensions. For standard cubes, volume was considered as:

$$\text{Volume} = (0.10 \times 0.10 \times 0.10 \ = 0.001\, m^3)$$

The hardened density was then calculated using the same formula as above:

$$DENSITY\ (kg/m^3) = \left(\frac{Mass\ of\ Cube\ (kg)}{Volume\ of\ cube\ (m^3)}\right)$$

Importance to the Study

Determining both the fresh and hardened densities is important in this research because palm kernel shell is significantly less dense than natural granite. This could result in lower concrete density, which may be advantageous for certain lightweight structural or non-load-bearing applications. However, density reduction must be carefully monitored to ensure that strength and durability are not compromised. These tests therefore helped provide a comprehensive understanding of the effect of PKS on the quality and performance of Grade 20 concrete.

3.8 COMPRESSIVE STRENGTH TEST

Concrete's compressive strength is widely regarded as the most important mechanical property in assessing its overall structural performance. The ability of a concrete mix to withstand axial loading is especially crucial in determining its suitability for various applications, including slabs, pavements, foundations, and load-bearing walls. In this study, the compressive strength test was conducted on Grade 20 concrete specimens containing varying percentages of palm kernel shell (PKS) as a partial replacement for coarse aggregate.

This test was essential to determine how the inclusion of PKS affects the load-bearing capacity of the concrete. Since PKS is lighter and more porous than natural granite, it was important to verify whether its use at different proportions would still allow the concrete to meet or exceed the 20 MPa strength threshold.

Objective of the Test

To determine the compressive strength of concrete samples with 0%, 10%, 20%, and 30% partial replacement of granite by palm kernel shell after curing periods, especially at 7 and 28 days.

Standard Referenced

i. **BS EN 12390-3:2019** – Testing hardened concrete – Part 3: Compressive strength of test specimens

3.8.1 Apparatus And Equipment

1. Concrete cube moulds (100 mm × 100 mm × 100 mm)
2. Compression testing machine (CTM) with a minimum capacity of 2000 kN
3. Trowel and compacting rod
4. Curing tank
5. Weighing scale
6. Digital timer
7. Caliper (optional for accuracy)

3.8.2 Preparation Of Specimens

1. Concrete was mixed based on a standard mix ratio suitable for Grade 20 concrete, with granite partially replaced by PKS in four batches: 0%, 10%, 20%, and 30%.
2. For each mix, concrete was placed into cube moulds in three layers, with each layer compacted using a standard tamping rod or table vibrator.

3. The top surface was leveled with a trowel to ensure a smooth finish.
4. The moulds were left undisturbed for 24 hours in a shaded environment at room temperature.

3.8.3 Curing Of Specimens

After demoulding at 24 hours, the cubes were transferred into a curing tank filled with clean water. The curing periods were 7 and 28 days to observe strength gain over time. Water temperature was maintained as closely as possible to 20 ± 2°C, in line with standard practice.

3.8.4 Test Procedure

1. At the end of each curing period, the concrete cubes were removed from the tank, wiped clean to remove excess water, and labeled.
2. Each specimen was placed centrally in the compression testing machine.
3. Load was applied gradually and uniformly at a rate of approximately 0.6 ± 0.2 MPa/s until failure occurred.
4. The maximum load at failure was recorded.
5. The compressive strength was calculated using the formula:

$$Compressive\ strength\ (MPa) = \frac{Maximum\ load}{Loaded\ area}$$

For standard 100 mm cubes, the loaded area is: $100 \times 100 = 10000mm^2$

The average strength was determined for each batch (three cubes per mix at each curing period), and results were compared to assess the effect of PKS replacement on compressive strength.

Relevance to the Study

This test served as a primary indicator of how well palm kernel shell performs as a substitute for granite in structural concrete. Any significant drop in compressive strength could limit the use of PKS to non-load-bearing elements, while results close to or above 20 MPa would support its potential for broader application. Tracking strength at both 7 and 28 days also allowed insight into the early and long-term performance of the material, particularly in relation to hydration and curing characteristics.

CHAPTER FOUR

This chapter entails comprehensive results from each experimental test that was carried out. Necessary graphs are also included to show how the experiment performed compared to others.

4.1 SIEVE ANALYSIS TEST RESULTS

TABLE 4.1: SIEVE ANALYSIS FOR COARSE AGGREGATE (GRANITE)

Sieve No	Mass of aggregate retained (g)	Percentage of aggregate retained (%)	Cumulative Percentage of aggregate retained (%)	Cumulative Percentage of aggregate Passing (%)
20mm	0.765	25.50	25.50	74.50
14mm	1.830	61.00	86.50	13.50
10mm	0.286	9.53	96.03	3.97
8mm	0.040	1.33	97.36	2.64
5mm	0.053	1.77	99.13	0.87
Pan	0.026	0.87	00	0
TOTAL	3.000			

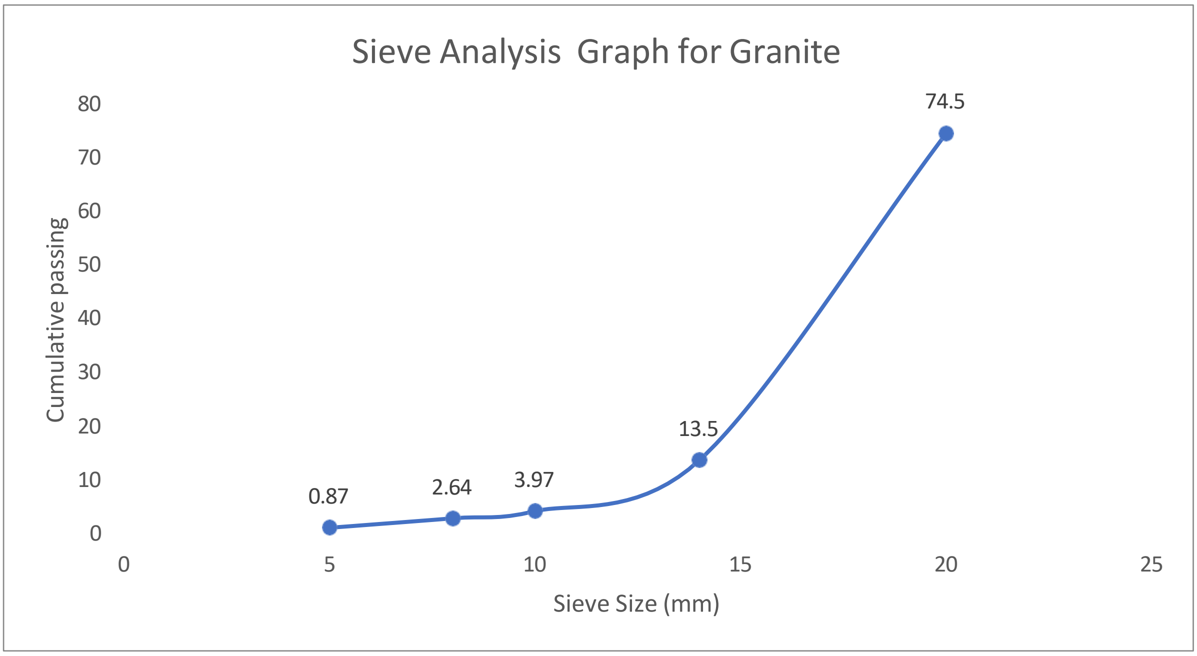


PLATE 4.1 SIEVE ANALYSIS CHART FOR GRANITE

TABLE 4.2: SIEVE ANALYSIS FOR COARSE AGGREGATE (PALM KERNEL SHELL)

Sieve No	Mass of aggregate retained (g)	Percentage of Aggregate retained (%)	Cumulative Percentage of aggregate retained (%)	Cumulative Percentage of aggregate passed (%)
20mm	0.005	0.17	0.17	99.83
4mm	0.165	5.50	5.67	94.33
0mm	2.195	73.17	78.84	21.16
8mm	0.178	5.93	84.77	15.23
5mm	0.366	12.20	96.97	3.03
Pan	0.091	3.03	00	0
TOTAL	3.000			

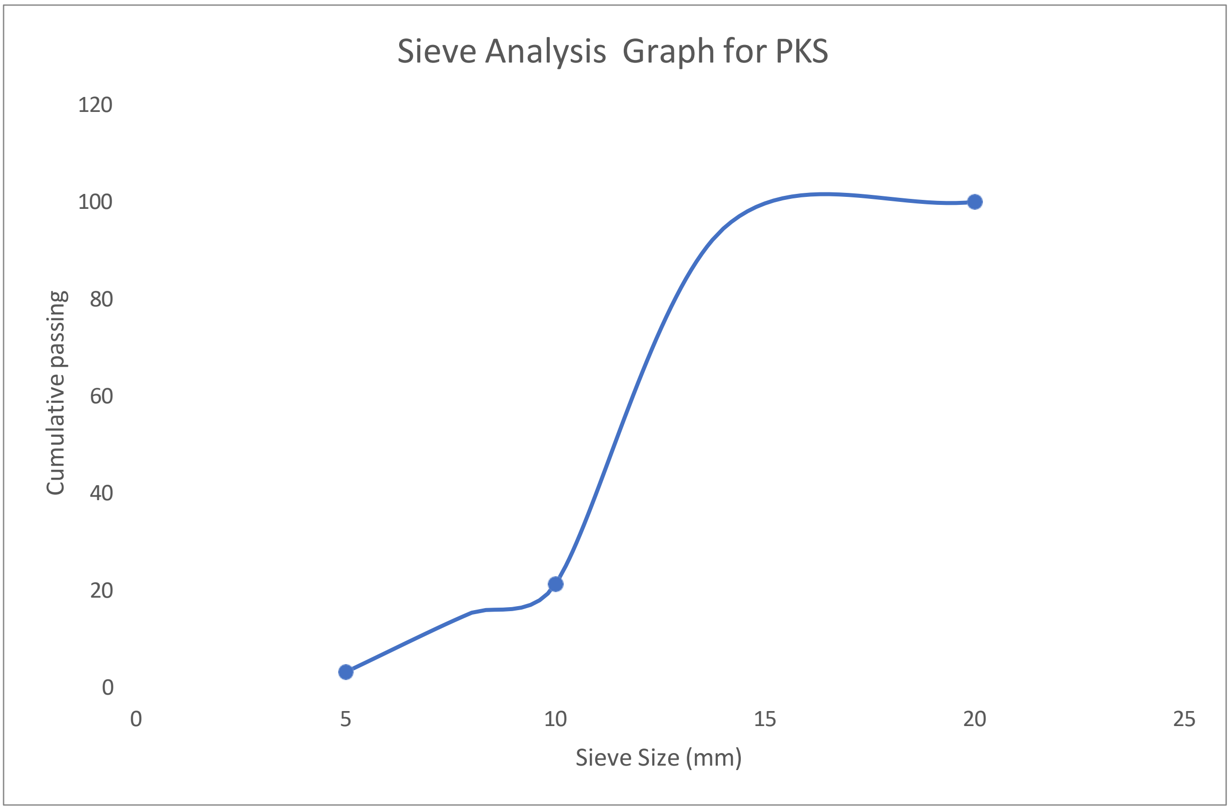


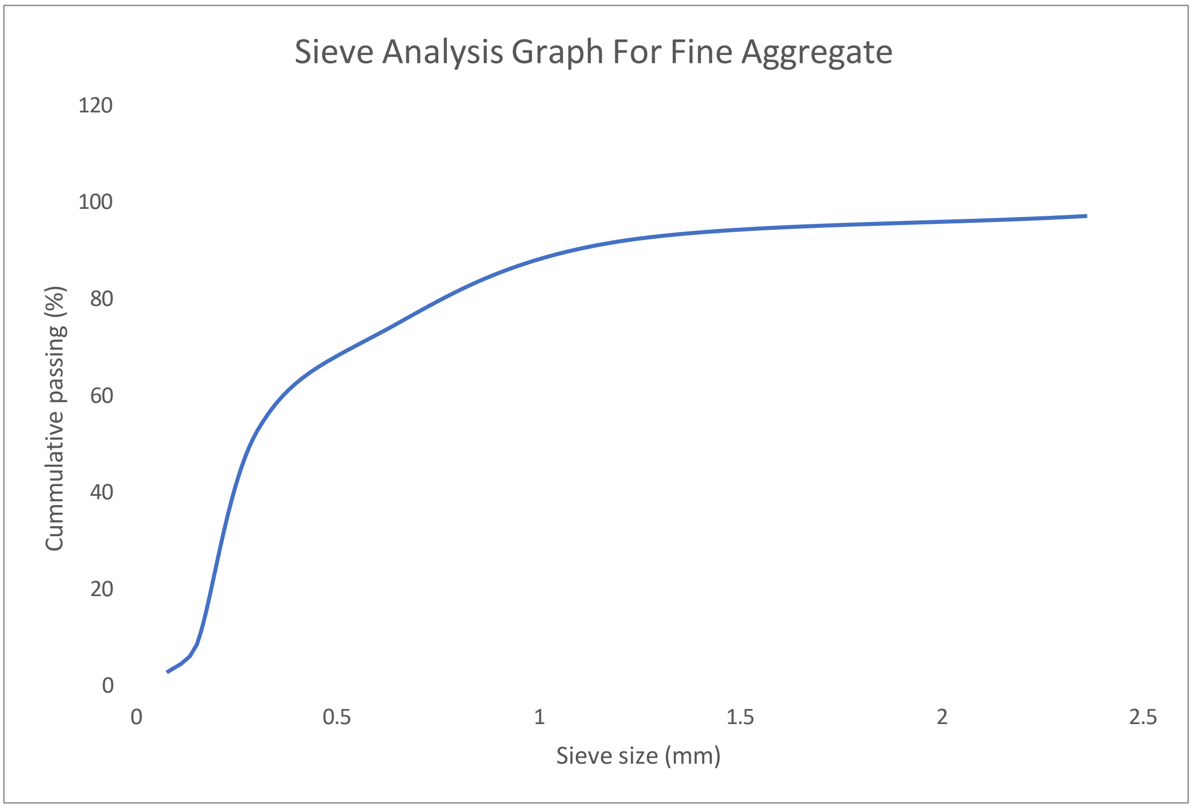
PLATE 4.2 SIEVE ANALYIS CHART FOR PKS

From the sieve analysis conducted, both granite and palm kernel shell were found to have acceptable particle size distribution for use as coarse aggregate. Granite showed better grading, while palm kernel shell had a wider spread of particle sizes. However, the grading of PKS was still within the recommended limits for concrete production.

TABLE 4.3: SIEVE ANALYSIS FOR FINE AGGREGATE

Sieve No	Mass of aggregate retained (g)	Percentage of aggregate retained (%)	Cumulative Percentage of aggregate retained (%)	Cumulative Percentage of aggregate Passing (%)
2.360	3.1	3.1	3.1	96.9
1.18	4.5	4.5	8.6	91.4
0.600	18.9	18.9	27.5	72.5
0.300	7.9	7.9	47.5	52.5
0.150	10.1	10.1	91.7	8.3
0.075	5.8	5.8	97.5	2.5

PLATE 4.3 SIEVE ANALYSIS CHART FOR FINE AGGREGATE



From the sieve analysis conducted, both granite and palm kernel shell were found to have acceptable particle size distribution for use as coarse aggregate. Granite showed better grading, while palm kernel shell had a wider spread of particle sizes. However, the grading of PKS was still within the recommended limits for concrete production.

4.2 SPECIFIC GRAVITY TEST RESULTS

TABLE 4.4: SPECIFIC GRAVITY FOR PALM KERNEL SHELL

Bottle No	Bottle Weight	Bottle + Soil (W_1)	Bottle + Soil + Water (W_2)	Bottle + Water (W_3)
E	594	764	140g + 1kg +500g +200g	2344
C	563	743	126g + 1kg +500g +200g	2300

TABLE 4.5: SPECIFIC GRAVITY FOR GRANITE

Bottle No	Bottle Weight	Bottle + Soil $((W_1))$	Bottle + Soil + Water (W_2)	Bottle + Water (W_3)
B	459	760	1881	2400
F	564	763	1900	2450

Specific Gravity Test Result

The specific gravity test results showed that palm kernel shell has a lower specific gravity than granite. This indicates that PKS is lighter in weight and accounts for the reduction in concrete weight when used as a partial replacement.

4.3 BULK DENSITY TEST RESULTS

TABLE 4.6: BULK DENSITY FOR COARSE AGGREGATE (GRANITE)

Test type	Empty container (kg)	Container + aggregate filled (kg)	Mass of aggregate (kg)	Bulk density (kg/m³)
Loose (no compaction)	2.50	10.13	7.63	7.63 ÷ 0.005 = 1526 kg/m³
Compacted (25 strokes/layer)	2.50	10.36	7.86	7.86 ÷ 0.005 = 1572 kg/m³

Sample calculation (compacted): Mass of aggregate = 10.36 − 2.50 = 7.86 kg
Bulk density = 7.86 / 0.005 = 1572 kg/m³

TABLE 4.7: BULK DENSITY FOR COARSE AGGREGATE (PKS)

Test type	Empty container (kg)	Container + aggregate filled (kg)	Mass of aggregate (kg)	Bulk density (kg/m³)
Loose (no compaction)	2.50	6.17	3.67	3.67 ÷ 0.005 = 734 kg/m³
Compacted (gentle tamping)	2.50	6.47	3.97	3.97 ÷ 0.005 = 794 kg/m³

Sample calculation (compacted): Mass of aggregate = 6.47 −2.50 = 3.97 kg

Bulk density = 3.97 / 0.005 = 794 kg/m³

TABLE 4.8: COMPARISON OF BULK DENSITY OF COARSE AGGREGATES

Aggregate	Loose bulk density (kg/m³)	Compacted bulk density (kg/m³)
Granite	1526	1572
Palm Kernel Shell (PKS)	734	794

Bulk Density Test Result

The bulk density results indicated that palm kernel shell has a lower bulk density compared to granite. This confirms the lightweight nature of PKS and its influence on reducing concrete density.

4.4 AGGREGATE IMPACT VALUE TEST RESULTS

TABLE 4.10: AGGREGATE IMPACT VALUE FOR COARSE AGGREGATE GRANITE

Weight of Dry Aggregate M1M_1M1 (g)	Weight Passing 2.36 mm M2M_2M2 (g)	Weight Retained M3M_3M3 (g)	M2+M3 (g)	Loss (g)	AIV (%)
3041.2	704	2334.9	3038.9	2.3	23.1
3102.1	712	2388.2	3100.2	1.9	22.9
3110.3	709	2399.3	3108.3	2.0	22.8

Mean AIV (%) = 22.96

TABLE 4.11: AGGREGATE IMPACT VALUE FOR COARSE AGGREGATE PALM KERNEL SHELL

Weight of Dry Aggregate M1M_1M1 (g)	Weight Passing 2.36 mm M2M_2M2 (g)	Weight Retained M3M_3M3 (g)	M2+M3 (g)	Loss (g)	AIV (%)
3040.5	940	2080	3020	20.5	30.9
3105.2	950	2120.1	3070.1	35.1	30.6
3112.8	960	2125.5	3085.5	27.3	30.8

Mean AIV (%) = 30.8

The Aggregate Impact Value (AIV) test revealed a distinct difference between granite and palm kernel shell (PKS). Granite exhibited a mean AIV of 22.96%, indicating high resistance to sudden impact and confirming its suitability as a strong and durable material for structural concrete. In contrast, PKS recorded a higher mean AIV of 30.8%, reflecting its more brittle and weaker nature under impact. This indicates that PKS is more prone to crushing when subjected to sudden loads. While PKS can still serve as a partial replacement for granite in Grade 20 concrete, its higher AIV suggests that increasing the PKS content in the mix may reduce the concrete's toughness. Therefore, the proportion of PKS in the mix should be carefully controlled to ensure satisfactory strength and performance. Overall, these results demonstrate that PKS possesses mechanical characteristics that differ significantly from granite, which must be considered in concrete mix design.

4.5 SLUMP TEST RESULTS

TABLE 4.12: SLUMP TEST

MIX	HEIGHT OF SLUMP (mm)
0% PKS	15
10% PKS	13
20% PKS	11
30% PKS	0

Slump Test Result

The slump test results indicated that workability decreased with increasing percentage of palm kernel shell. The control mix recorded the highest slump value, while mixes containing PKS showed lower slump values.

4.6 DENSITY TEST

TABLE 4.13: FRESH DENSITY TEST RESULTS

PKS Replacement Level (%)	Mass of Mold + Concrete (kg)	Mass of Empty Mold (kg)	Mass of Concrete (kg)	Volume of Mold (m³)	Fresh Density (kg/m³)
0 (Control)	3.59	1.00	2.59	0.001	2590
0 (Control) - Trial 2	3.61	1.00	2.61	0.001	2610
Average 0%					2600
10	3.56	1.00	2.56	0.001	2560
10 - Trial 2	3.54	1.00	2.54	0.001	2540
Average 10%					2550
20	3.29	1.00	2.29	0.001	2290
20 - Trial 2	3.27	1.00	2.27	0.001	2270
Average 20%					2280
30	3.23	1.00	2.23	0.001	2230
30	3.21	1.00	2.21	0.001	2210
Average 30%					2220

TABLE 4.14: HARDENED DENSITY TEST RESULTS (28-Day Curing)

PKS Replacement Level (%)	Cube Number	Mass of Cube (kg)	Volume of Cube (m³)	Hardened Density (kg/m³)	Average Hardened Density (kg/m³)
0 (Control)	4	2.637	0.001	2637	
0 (Control)	5	2.667	0.001	2667	
0 (Control)	6	2.624	0.001	2624	2643
10	4	2.629	0.001	2629	
10	5	2.611	0.001	2611	
10	6	2.606	0.001	2606	2615
20	4	2.361	0.001	2361	
20	5	2.322	0.001	2322	
20	6	2.330	0.001	2330	2338
30	4	2.261	0.001	2261	
30	5	2.311	0.001	2311	
30	6	2.263	0.001	2263	2278

Density Test Result

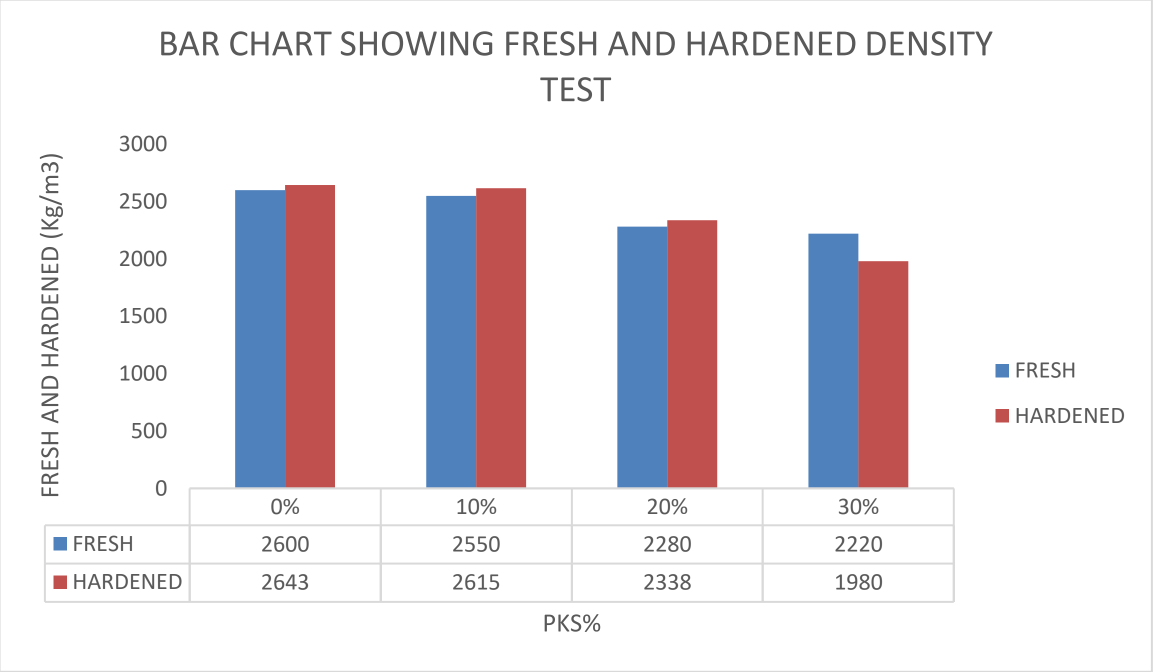
The density test results showed a gradual reduction in both fresh and hardened concrete density as the palm kernel shell content increased. This indicates that the use of PKS results in lighter concrete.

TABLE 4.15: FRESH AND HARDENED DENSITY RESULTS

PKS Replacement (%)	Fresh Density (kg/m³)	Hardened Density (kg/m³)	Difference (kg/m³)	Percentage Change (%)
0% (Control)	2600	2643	+43	+1.7
10%	2550	2615	+65	+2.5
20%	2280	2338	+58	+2.5
30%	2220	2278	+58	+2.6

Both fresh and hardened densities decreased as the percentage of PKS increased, reflecting the lightweight nature of the palm kernel shell compared to granite.

PLATE 4.4 DENSITY TEST CHART



4.7 COMPRESSIVE STRENGTH TEST RESULTS

COMPRESSIVE STRENGTH TEST FOR CONTROL (0%)

TABLE 4.16: COMPRESSIVE STRENGTH TEST FOR CONTROL (0%)

Percentage (Replacement Levels)	**Cube Number**	**Weight of Sample (Kg)**	**Density of Sample (Kg/m^{33})**	**Average density of Sample (Kg/m^{33})**	**Age Of Curing**	**Failure Loads (KN)**	**Compressive Strength (N/mm^{22})**	**Average Compressive Strength (N/mm^{22})**
0%	1	2.583	2583	2599	7	165.82	16.58	15.89
	2	2.610	2610			156.14	15.61	
	3	2.603	2603			154.86	15.48	
	4	2.637	2637		28	228.95	22.90	21.46
	5	2.667	2667			201.64	20.16	
	6	2.624	2624			213.17	21.32	

TABLE 4.17: COMPRESSIVE STRENGTH TEST FOR CONTROL (10%)

Percentage (Replacement Levels)	Cube Number	Weight of Sample (Kg)	Density of Sample (Kg/m^{33})	Average density of Sample (Kg/m^{33})	Age Of Curing	Failure Loads (KN)	Compressive Strength (N/mm^{22})	Average Compressive Strength (N/mm^{22})
10%	1	2.681	2681	2678	7	140.06	14.01	13.67
	2	2.747	2747			133.10	13.31	
	3	2.606	2606			136.87	13.69	
	4	2.629	2629	2615	28	212.92	21.29	19.21
	5	2.611	2611			184.19	18.42	
	6	2.606	2606			199.33	19.21	

TABLE 4.18: COMPRESSIVE STRENGTH TEST FOR CONTROL (20%)

Percentage (Replacement Levels)	Cube Number	Weight of Sample (Kg)	Density Of Sample (Kg/m^{33})	Average density of Sample (Kg/m^{33})	Age of Curing	Failure Loads (KN)	Compressive Strength (N/mm^{22})	Average Compressive Strength (N/mm^{22})
20%	1	2.283	2283	2273	7	100.77	10.08	10.06
	2	2.309	2309			115.59	11.56	
	3	2.227	2227			103.46	10.35	
	4	2.361	2361	2338	28	154.64	15.46	15.18
	5	2.322	2322			130.77	13.08	
	6	2.330	2330			170.11	17.01	

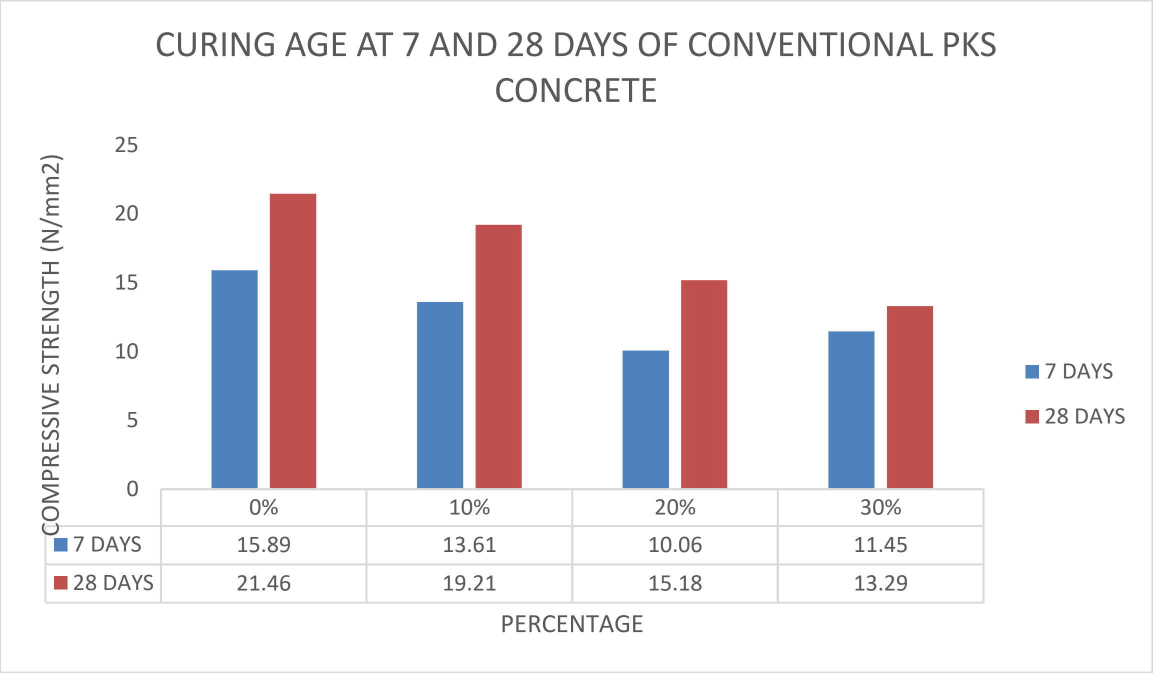
TABLE 4.19: COMPRESSIVE STRENGTH TEST FOR CONTROL (30%)

Percentage (Replacement Levels)	**Cube Number**	**Weight of Sample (Kg)**	**Density of Sample (Kg/m^{33})**	**Average density of Sample (Kg/m^{33})**	**Age of Curing**	**Failure Loads (KN)**	**Compressive Strength (N/mm^{22})**	**Average Compressive Strength (N/mm^{22})**
30%	1	2.247	2247	2317	7	75.303	7.53	11.45
	2	2.292	2292			136.27	13.63	
	3	2.413	2413			131.87	13.19	
	4	2.261	2261	2278	28	171.42	17.14	13.29
	5	2.311	2311			102.89	10.29	
	6	2.263	2263			124.53	12.45	

Compressive Strength Test Result

The compressive strength results showed an increase in strength with curing age for all mixes. However, strength reduced as the percentage of palm kernel shell increased. Concrete containing up to 20% PKS achieved compressive strength values close to the control mix at 28 days.

PLATE 4.5 COMPRESSIVE STRENGTH CHART



	0%	10%	20%	30%
🟦 7 DAYS	15.89	13.61	10.06	11.45
🟥 28 DAYS	21.46	19.21	15.18	13.29

CHAPTER FIVE

5.1 CONCLUSION

This study assessed the partial replacement of granite with palm kernel shell (PKS) in Grade 20 concrete at different replacement levels of 0%, 10%, 20%, and 30%. The experimental results showed that PKS has unique physical and mechanical properties that affect the performance of concrete.

The sieve analysis showed that PKS particles were generally well-graded within the acceptable limits for coarse aggregates, although more irregular in shape compared to granite. The specific gravity and bulk density tests confirmed that PKS is significantly lighter, with an average compacted bulk density of 794 kg/m^3 compared to granite's 1572 kg/m^3, indicating its potential as a lightweight aggregate.

The water absorption test results reveal a significant difference between the two aggregate types. Granite exhibited an average water absorption of 1.35%, which is typical for natural crushed stone aggregates and falls within the acceptable range of 0.5-2.0% specified in BS 812-2:1995. This low absorption rate indicates that granite is a dense, non-porous material that requires minimal additional water during concrete mixing.. The Aggregate Impact Value (AIV) test further revealed that PKS is less tough than granite, with an AIV of 30.8% compared to granite's 22.96%, reflecting lower impact resistance but acceptable performance for non-critical structural applications.

Workability decreased progressively with higher PKS content, as seen from the slump test values dropping from 15 mm at 0% to 0 mm at 30% replacement. Similarly, both fresh and hardened densities reduced with increasing PKS content due to the material's lower specific gravity, confirming its suitability for lightweight concrete production.

Compressive strength results indicated that the control mix (0% PKS) achieved an average of 21.46 N/mm^2 at 28 days, meeting the Grade 20 requirement. The 10% and 20% PKS mixes achieved
19.21 N/mm^2 and slightly lower values respectively, still within acceptable limits for non-load-bearing and moderate-strength applications. However, the 30% PKS mix showed a significant reduction, indicating that excessive replacement compromises structural strength.

Overall, the study concludes that palm kernel shell can effectively replace up to 20% of granite in Grade 20 concrete without severely affecting strength or durability. This demonstrates its potential as an eco-friendly, cost-effective alternative aggregate that promotes sustainable construction and reduces agricultural waste pollution.

5.2 RECOMMENDATIONS

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

1. **For construction practitioners:**

a. PKS can be safely used to replace up to 20% of granite in Grade 20 concrete for lightweight and non-load-bearing applications such as walkways, floor slabs, pavements, and partition walls.

b. Proper mix design adjustments should be made to account for PKS's high water absorption, possibly using water-reducing admixtures like polycarboxylate ether (PCE) superplasticizers to maintain workability.

2. **For government and regulatory agencies:**

a. Standards should be developed and incorporated into building codes to guide the use of agricultural waste materials like PKS in concrete production.

b. Policies that encourage sustainable construction and recycling of agricultural by- products should be promoted to reduce environmental waste.

3. **For corporate organizations and industries:**

a. Palm oil processing companies should collaborate with the construction sector to supply treated PKS as an alternative aggregate, creating a circular economy and reducing waste disposal costs.

b. Construction firms should explore PKS concrete for affordable housing projects to reduce material costs and promote sustainability.

4. **For academic institutions:**

a. Engineering departments should include laboratory-based studies on waste-derived aggregates in their curricula to encourage innovation in sustainable materials.

5.3 AREAS FOR FURTHER RESEARCH

This study was limited to the mechanical properties of Grade 20 concrete with PKS replacement levels up to 30%. To broaden understanding and application, future researchers are encouraged to investigate the following areas:

1. The effect of higher replacement levels (above 30%) of PKS on the long-term strength, durability, and microstructure of concrete.
2. The use of chemical treatments or surface coatings to reduce the water absorption of PKS and improve bonding with cement paste.
3. The performance of PKS concrete under varying curing conditions and environmental exposures such as freeze–thaw, sulfate attack, or marine environments.
4. The use of non-destructive testing methods such as ultrasonic pulse velocity (UPV) to evaluate the internal integrity of PKS concrete.
5. The potential of combining PKS with other waste materials (e.g., periwinkle shells, coconut shells, or fly ash) to produce hybrid sustainable concrete.

REFERENCES

Akinmusuru, J. O., and Adamu, A. A. (2023) 'Effect of agricultural waste aggregates on the strength of concrete: A comparative study of coconut shell and palm kernel shell', *Journal of Building Materials* and *Structures*, 10(1), pp. 56–65.

Amartey, B. H. S., Taku, K. J., and Amartey, Y. D. (2023) 'Mechanical Properties of Palm Kernel Shell Ash Blended Cement Concrete', *FUDMA Journal of Sciences*, 7(6), pp. 32–40.

Boateng, K., Owusu-Afriyie, J., and Danso, H. (2023) 'Investigating lightweight concrete made from agricultural waste aggregates', *Construction* and *Building Materials*, 369, 130422. https://doi.org/10.1016/j.conbuildmat.2023.130422

British Standards Institution. (1985) *BS 812-103.1:1985 – Testing aggregates. Method for determination of particle size distribution*. London: BSI.

British Standards Institution. (1990a) *BS 812-110:1990 – Testing aggregates. Methods for determination of aggregate crushing value (ACV)*. London: BSI.

British Standards Institution. (1990b) *BS 812-112:1990 – Testing aggregates. Method for determination of aggregate impact value (AIV)*. London: BSI.

British Standards Institution. (1992) *BS 882:1992 – Specification for aggregates from natural sources for concrete*. London: BSI.

British Standards Institution. (1995) *BS 812-2:1995 – Testing aggregates. Methods for determination of density* and *water absorption*. London: BSI.

British Standards Institution. (1998) *BS EN 1097-3:1998 – Tests for mechanical* and *physical properties of aggregates – Part 3: Determination of loose bulk density* and *voids*. London: BSI.

British Standards Institution. (2002) *BS EN 1008:2002 – Mixing water for concrete – Specification for sampling, testing* and *assessing the suitability of water*. London: BSI.

British Standards Institution. (2009a) *BS EN 12350-2:2009 – Testing fresh concrete – Part 2: Slump test*. London: BSI.

British Standards Institution. (2009b) *BS EN 12350-6:2009 – Testing fresh concrete – Part 6: Density*. London: BSI.

British Standards Institution. (2009c) *BS EN 12390-3:2009 – Testing hardened concrete – Part 3: Compressive strength of test specimens*. London: BSI.

British Standards Institution. (2009d) *BS EN 12390-7:2009 – Testing hardened concrete – Part 7: Density of hardened concrete*. London: BSI.

British Standards Institution. (2011) *BS EN 197-1:2011 – Cement – Part 1: Composition, specifications* and *conformity criteria for common cements*. London: BSI.

British Standards Institution. (2012a) *BS EN 933-1:2012 – Tests for geometrical properties of aggregates – Part 1: Determination of particle size distribution*. London: BSI.

British Standards Institution. (2012b) *BS EN 934-2:2012 – Admixtures for concrete, mortar* and *grout – Part 2: Concrete admixtures – Definitions, requirements, conformity, marking* and *labelling*. London: BSI.

British Standards Institution. (2013a) *BS EN 1097-6:2013 – Tests for mechanical* and *physical properties of aggregates – Part 6: Determination of particle density* and *water absorption*. London: BSI.

British Standards Institution. (2013b) *BS EN 12620:2013 – Aggregates for concrete*. London: BSI.

British Standards Institution. (2019) *BS EN 12390-3:2019 – Testing hardened concrete – Compressive strength of test specimens*. London: BSI.

Chen, L., and Gao, Y. (2023) ‘Effects of water–cement ratio on mechanical properties of manufactured sand concrete’, *Construction* and *Building Materials*, 365, 130037. https://doi.org/10.1016/j.conbuildmat.2023.130037

Fapohunda, C., Bello, H., and Salako, T. (2022) ‘Strength investigations of concrete with palm kernel shell as partial coarse aggregate replacement’, *Engineering Review*, (1251), pp. 87–95.

Fapohunda, C., Bello, H., Salako, T., and Tijani, S. (2022) ‘Strength, microstructure, and durability investigations of lateritic concrete with palm kernel shell as partial replacement of coarse aggregates’, *Engineering Review*, 42(1), pp. 1251–1264.

Fapohunda, C., Salako, T., and Tijani, S. (2023) ‘Durability performance of foamed concrete incorporating agricultural waste materials’, *Journal of Sustainable Construction Materials* and *Technologies*, 8(1), pp. 19–27.

Financial Times. (2024) ‘New tech firms tackle cement industry’s carbon footprint’. Available at: https://www.ft.com

Ifeanyi, O. E., Chima, A. D., and Chukwudubem, N. J. (2023) ‘Structural Behavior of Concrete Produced Using Palm Kernel Shell as Partial Substitute for Coarse Aggregate’, *American Journal of Innovation in Science* and *Engineering*, 2(1), pp. 1–7.

Kolo, D. N., Tsado, T. Y., and Abbas, B. A. (2022) ‘Models to Predict the Fresh and Hardened Properties of Palm Kernel Shell Concrete’, *Malaysian Journal of Civil Engineering*, 34(1),

pp. 29–35.

Muomaife, O. K. D. (2021) *Use of Palm Kernel Shell as an Aggregate in Concrete Mixture*.

Undergraduate Project, Department of Civil Engineering, Nnamdi Azikiwe University.

Neville, A. M. (2011) *Properties of Concrete* (5th ed.). Harlow, England: Pearson Education Limited.

Neville, A. M., and Brooks, J. J. (2010) *Concrete technology* (2nd ed.). Pearson Education.

Odeyemi, S. O., Abdulwahab, R., Abdulsalam, A. A., and Anifowose, M. A. (2024) ‘Bond and Flexural Strength Characteristics of Partially Replaced Self-Compacting Palm Kernel Shell Concrete’, *Malaysian Journal of Civil Engineering*, 31.

https://doi.org/10.11113/mjce.v31.16085

Ohene-Coffie, F., Kankam, C. K., Kpo, S. A. K., Boateng, G. O., and Nanor, E. S. (2024) ‘Anchorage Bond Strength of Glass Fibre Polymer Reinforced Concrete with Palm Kernel Shells as Partial Coarse Aggregate’, *Journal of Engineering Research* and *Reports*, 26(7), pp. 1–16. https://doi.org/10.9734/jerr/2024/v26i71189

Olusola, K. O., and Babafemi, A. J. (2022) ‘Effect of Coarse Aggregate Sizes and Replacement Levels on the Strength of Palm Kernel Shell Concrete’, *Civil Engineering Dimension*, 15(1), pp. 43–50.

Olusola, K. O., and Babafemi, A. J. (2022) ‘Influence of palm kernel shell size and replacement levels on mechanical properties of concrete’, *IISTE Journal of Civil* and *Environmental Research*, 14(3), pp. 1–10.

Osamuyi, O., Nwankwo, E., and Iyoha, P. (2021) ‘Suitability of Periwinkle Shell Mixed with Palm Kernel Shell Wastes as Replacement for Coarse Aggregate’, *Journal of Energy Technology* and *Environment*, 3(3).

Reuters. (2023) ‘Cement startups aim to reduce emissions with new technologies’. Available at: https://www.reuters.com

Sahputra, E., Ramli, M., and Sulaiman, M. (2023) ‘Evaluation of mechanical properties of lightweight concrete using palm kernel shell’, *CIGR Journal*, 25(2), pp. 63–71.

Sahputra, M., Putra, A. R., and Hasan, R. (2023) ‘Utilization of palm kernel shell as coarse aggregate in lightweight concrete’, *Journal of Sustainable Civil Engineering*, 9(2), pp. 100–109.

Scrivener, K. L., Martirena, F., Bishnoi, S., and Maity, S. (2018) ‘Calcined clay limestone cements (LC^3)’, *Cement* and *Concrete Research*, 114, pp. 49–56. https://doi.org/10.1016/j.cemconres.2017.08.017

The Times. (2024) ‘Amsterdam opens cement plant targeting 1 million tonne CO_2 savings’.
Available at: https://www.thetimes.co.uk

Tianjin University. (2024) *Performance of polycarboxylate superplasticizers in low-w/c ratio concrete*. Department of Civil Engineering, Tianjin University.

Usman, N. D., Idusuyi, F. I., Ojo, E. B., and Simon, B. (2022) ‘The use of sawdust and palm kernel shell as substitutes for fine and coarse aggregates in concrete construction’, *Journal of Civil* and *Materials Engineering Practice (JCMEP)*, 2(3), pp. 45–53.

Yiwo, E., Tamayo, P., Jato-Espino, D., García Del Angel, G., and Thomas, C. (2023) ‘The Effect of Untreated Dura-Palm Kernel Shells as Coarse Aggregate in Lightweight Pervious Concrete’, *Buildings*, 13(7), 1588.

Yusuf, I. T., and Jimoh, Y. A. (2023) ‘Modeling Residual Strength of Palm Kernel Shell Concrete Using the Ultrasonic Pulse Velocity for Rigid Pavement Maintenance’, *Malaysian Journal of Civil Engineering*, 27. https://doi.org/10.11113/mjce.v27.15924

Yusuf, M. O., and Jimoh, A. A. (2023) ‘Environmental impacts of granite quarrying and sustainable alternatives in Nigeria’, *Nigerian Journal of Environmental Technology*, 5(2), pp. 112–120.

Zhao, X., Li, H., and Zhang, Y. (2024) ‘Chloride penetration in concrete under varying w/b ratios and environmental cycles’, *Journal of Materials in Civil Engineering*, 36(2), 04024003. https://doi.org/10.1061/(ASCE)MT.1943-5533.0004691

APPENDIX

PLATE 5.1 CURING TANK

PLATE 5.2 FILLING THE MOULD

PLATE 5.3 SLUMP TEST

PLATE 5.4 WATER ABSORPTION TEST

PLATE 5.5 BULK DENSITY TEST

PLATE 5.6 MEASURING OF COARSE AGREGATE