EVALUATION OF WATER ABSORPTION AND DENSITY OF HYBRID FOAM CONCRETE USING PALM KERNEL OIL SURFACTANT.

BY

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HND/23/CEC/FT/0028

BEING IN RESEARCH WORK SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING, INSTITUTE OF TECHNOLOGY, KWARA STATE POLYTECHNIC, ILORIN

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF HIGHER NATIONAL DIPLOMA (HND) IN CIVIL ENGINEERING

JULY, 2025.

CERTIFICATION

This is to certify that this research study was conducted by ABDULQUADRI, Ibrahim Olamide (HND/23/CEC/FT/0028**)** and had been read and approved as meeting the requirement for the award of Higher National Diploma (HND) in Civil Engineering of the Department Civil Engineering, Institute of Technology, Kwara State Polytechnic, Ilorin.

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I hereby declare that this project work titled EVALUATION OF WATER ABSORPTION AND DENSITY OF HYBRID FOAM CONCRETE USING PALM KERNEL OIL SURFACTANT is a work done by me, Abdulquadri Ibrahim Olamide with matric number, HND/23/CEC/FT/0028 of the Department of Civil Engineering, Institute of Technology, Kwara State Polytechnic, Ilorin.

____________________ ________________

Signature Date

DEDICATION

This project is dedicated solemnly to God Almighty, who is the sole inspiration of all things, without whom there would not be, and neither would this project.

Appreciation goes to my loving parents for their support in the fulfillment of my Higher National Diploma (HND) both orally and financially. May God allow them to eat the fruit of their labor (Amen)

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I express my profound gratitude to God in heaven, Alpha and Omega for the protection and support to finish the HND program successfully.

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ABSTRACT

This study investigates the effect of palm kernel oil-based surfactant (PKOS) on the water absorption and density of hybrid foam concrete. The aim is to determine the feasibility of using PKOS as a natural, eco-friendly foaming agent in concrete to achieve lightweight and durable construction materials. A mixture of Portland Limestone Cement, stone dust, sand, water, sodium lauryl sulfate (SLS), and varying percentages of PKOS (0%, 1.5%, and 3%) was prepared and tested. The concrete was evaluated for both fresh properties (workability and fresh density) and hardened properties (dry density and water absorption). The slump test results showed that increasing PKOS reduced workability, with slump values ranging from 120 mm to 90 mm. Fresh density increased with higher PKOS concentration, reaching up to 2200 kg/m³, indicating improved foam structure. Conversely, dry density decreased from 1921 kg/m³ to 1829 kg/m³ with increasing PKOS content, demonstrating a reduction in weight. Water absorption also decreased from 2.24% to 1.89%, reflecting enhanced resistance to moisture penetration. The findings reveal that PKOS enhances the performance of foam concrete by improving its physical properties and sustainability profile. An optimal dosage of 1.5–3.0% PKOS is recommended for balancing durability and lightweight characteristics in construction applications.

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CHAPTER ONE

INTRODUCTION

1.1 Background of The Study

In recent years, sustainable construction practices have gained significant attention due to growing environmental concerns and the need to reduce the carbon footprint of the building industry (Yusof & Zulkifli, 2022). Among various sustainable building materials, foam concrete has emerged as an innovative and eco-friendly option, widely used for both structural and non-structural applications. It is a lightweight, cement-based material that contains a high volume of air voids, introduced through the use of foaming agents or surfactants (Jones & McCarthy, 2005). These voids significantly reduce the density of the concrete while offering benefits such as improved thermal insulation, sound absorption, and reduced dead loads (Chandra & Berntsson, 2002).

Traditionally, foam concrete relies on synthetic surfactants—chemicals that stabilize the foam mixture—to produce a homogenous and stable matrix. However, synthetic surfactants often come with environmental and health concerns, including non-biodegradability and potential toxicity (Ibrahim et al., 2021). As a result, there is growing interest in exploring natural and biodegradable alternatives, particularly those derived from renewable agricultural sources.

Palm kernel oil, a by-product of the palm oil industry, is one such renewable resource. Surfactants derived from palm kernel oil are biodegradable, environmentally friendly, and readily available in palm oil-producing regions (Oyejobi et al., 2018). These natural surfactants have the potential to replace synthetic ones in foam concrete applications, thus promoting sustainability and reducing reliance on petroleum-based chemicals (Mohammed et al., 2022).

Despite its promising benefits, the use of palm kernel oil surfactants in foam concrete remains underexplored, particularly with regard to how they influence key material properties such as density and water absorption. These two parameters are critical in assessing the performance, durability, and applicability of foam concrete in various environments (Neville, 2011; Rahman et al., 2021).

1.2 Problem Statement

While foam concrete offers numerous advantages, its long-term performance is highly dependent on its physical properties. Density affects the strength, thermal conductivity, and structural application of the material, while water absorption relates directly to its durability, especially in moist or aggressive environments (Jones & McCarthy, 2005). The incorporation of natural surfactants such as palm kernel oil into the foam concrete mix may alter these characteristics (Akinshipe & Akinyemi, 2020).

Currently, there is limited research available on how palm kernel oil-based surfactants affect the density and water absorption behavior of hybrid foam concrete (Oyejobi et al., 2018). Without such understanding, the wider adoption of eco-friendly surfactants in foam concrete production may be hindered. Therefore, it is essential to evaluate the effectiveness and impact of palm kernel oil surfactants on these critical properties to determine their viability as a sustainable alternative.

The demand for sustainable and lightweight construction materials has increased significantly due to environmental concerns and the need for energy-efficient structures (Yusof & Zulkifli, 2022). Foam concrete, known for its low density and good thermal insulation properties, has emerged as a promising material in this context. However, conventional foam concrete often exhibits high water absorption and inconsistent density, which can compromise its structural integrity and durability (Neville, 2011).

Incorporating natural and eco-friendly surfactants, such as palm kernel oil (PKO) derivatives, into foam concrete production presents an innovative approach to enhance its properties while promoting the use of renewable resources. Despite the potential benefits, limited research exists on the effect of palm kernel oil surfactant on the water absorption and density behavior of hybrid foam concrete (Ibrahim et al., 2021; Rahman et al., 2021).

Therefore, it is imperative to systematically evaluate how palm kernel oil surfactant influences the water absorption capacity and density characteristics of hybrid foam concrete to determine its suitability for sustainable construction applications (Mohammed et al., 2022).

1.3 Aim and Objectives

The aim of this study is to evaluate water absorption and density of hybrid foam concrete using palm kernel oil surfactant.

The objectives are as follow:

1. Evaluate the influence of palm kernel oil on the workability of hybrid foam concrete.
2. Evaluate the impact of palm kernel oil surfactant on water density of hybrid foam concrete.
3. Investigate the influence of palm kernel oil surfactant on water absorption of hybrid foam concrete.
4. Compare the results with and without palm kernel oil surfactant.

1.4 Scope of the Study

This study focuses on evaluating the water absorption and density characteristics of hybrid foam concrete produced using palm kernel oil (PKO) surfactant as a foaming agent. The investigation is limited to the following aspects:

- **Mix Proportions**: Specific mix ratios of foam concrete incorporating varying percentages of PKO surfactant will be prepared and tested to determine the optimal mix for density and water absorption performance (Akinshipe & Akinyemi, 2020).
- **Physical Properties Assessment**: The study focuses only on the evaluation of density (both fresh and hardened state) and water absorption according to relevant standards (e.g., ASTM, BS) (Neville, 2011).
- **Experimental Methodology**: Laboratory-scale tests will be conducted. The results will not account for field performance or long-term durability beyond water absorption and density.
- **Geographical Limitation**: The research is limited to materials available within the study location and does not account for variations due to climatic or environmental conditions elsewhere.

- **Time Frame**: The study covers short-term properties (up to 28 days of curing). Long-term durability, mechanical strength, or environmental impacts are outside the current scope (Jones & McCarthy, 2005).

1.5 Significance of the Study

This study holds significant value in advancing sustainable construction materials by exploring the use of palm kernel oil-based surfactant in the production of hybrid foam concrete (Yusof & Zulkifli, 2022). By evaluating the water absorption and density properties, the research aims to provide insights into the performance, durability, and potential applications of this eco-friendly material (Mohammed et al., 2022; Rahman et al., 2021).

The findings can contribute to reducing the reliance on conventional chemical foaming agents, lowering environmental impacts, and promoting the utilization of renewable agricultural by-products (Oyejobi et al., 2018). Additionally, the study may support the development of lightweight, energy-efficient, and cost-effective construction materials suitable for various structural and non-structural applications, thereby benefiting the construction industry, environmental management, and local economies (Akinshipe & Akinyemi, 2020; Ibrahim et al., 2021).

CHAPTER TWO

LITERATURE REVIEW

2.1 Preamble

Foam concrete is a versatile, lightweight material increasingly used in construction for its beneficial properties such as low density, thermal insulation, and ease of placement (Jones & McCarthy, 2005). With growing interest in sustainable and cost-effective materials, hybrid foam concretes incorporating natural surfactants like palm kernel oil (PKO) are under investigation. This review explores past studies on the materials used, fresh and hardened properties, and the overall performance of foam concrete (Amran et al., 2015).

2.2 Materials in Foam Concrete

2.2.1 Cement

Ordinary Portland Cement (OPC) is the primary binder used in foam concrete. It undergoes hydration to form the matrix that holds aggregates and entrapped air bubbles. Supplementary cementitious materials (SCMs) such as fly ash, slag, and silica fume have also been introduced to improve durability and reduce CO_2 emissions (Neville, 2011).

2.2.2 Aggregate

Foam concrete typically uses fine aggregates like river sand or quarry dust. The absence of coarse aggregates contributes to its lightweight nature. Particle size distribution plays a critical role in optimizing workability and strength (Chandra & Berntsson, 2002).

2.2.3 Foam Agents

Foaming agents are central to foam concrete technology. Synthetic agents such as sodium lauryl sulfate offer high stability but pose environmental concerns. In contrast, PKO-based surfactants have been recognized for their biodegradability and ability to generate acceptable foam (Ibrahim et al., 2021; Oyejobi et al., 2018).

2.3 Properties of Fresh Foam Concrete

Workability

Workability influences ease of mixing and placement. It is determined by water-to-cement ratio, foam quality, and surfactant type (Mohammed et al., 2022).

Consistency

Stable foam and proper mix ratios enhance consistency across applications (Jones & McCarthy, 2005).

Stability

The foam must remain stable during mixing and setting to ensure a uniform pore structure. Studies have shown that PKO-based surfactants retain foam structure adequately for forming consistent matrices (Hassan et al., 2020).

Compatibility

While foam concrete is generally self-compacting, the surfactant must integrate well with the cementitious matrix to avoid segregation (Ahmed et al., 2022).

2.4 Physical Properties of Foam Concrete

Density

Foam concrete's density typically ranges between 300 and 1,800 kg/m^3. It is significantly affected by foam volume and surfactant type (Jones & McCarthy, 2005). PKO-based foam concretes, when optimized, can achieve similar densities to those made with synthetic foams (Mohammed et al., 2022).

Drying Shrinkage

Shrinkage due to water evaporation can lead to cracking. Proper foam stability and curing reduce shrinkage risk (Neville, 2011).

Water Absorption

Water absorption reflects pore connectivity and porosity. Foam concretes made with PKO show promising results in reducing water absorption, especially when combined with pozzolans (Chokri et al., 2019; Rahman et al., 2021).

2.5 Mechanical Properties of Foam Concrete

Compressive Strength

Compressive strength is lower than in traditional concrete but sufficient for many applications. Hybrid mixes with PKO and SCMs such as fly ash or silica fume can improve compressive strength (Akinshipe & Akinyemi, 2020).

Flexural Strength

Fiber reinforcement and optimized pore structure enhance flexural strength, important for lightweight partitions (Musa et al., 2021).

2.6 Durability of Foam Concrete

Thermal Conductivity

Low thermal conductivity makes foam concrete suitable for insulation. Surfactant chemistry and air-void structure directly impact thermal behavior (Amran et al., 2015).

Elevated Temperature Resistance

Foam concrete retains stability under heat due to its porous nature. PKO-based concrete has shown moderate performance in thermal resistance tests (Rahmat & Singh, 2023).

Acoustic Properties

Its cellular structure provides excellent sound absorption, useful in buildings requiring noise control (Lim et al., 2021).

2.7 Palm Kernel Oil Surfactant in Foam Concrete

PKO-based surfactants are derived from the oil palm industry and present a renewable, biodegradable alternative to synthetic foaming agents (Oyejobi et al., 2018). They contain fatty acids like lauric and myristic acid, which contribute to their foaming ability (Hassan et al., 2020). Studies show PKO surfactants can produce foam concrete with comparable performance to synthetic agents in terms of density and water resistance (Ibrahim et al., 2021; Chandra et al., 2019).

2.8 Hybrid Foam Concrete with PKO Surfactant

Hybrid foam concrete incorporates additives such as SCMs or fibers to improve performance. PKO surfactants used in combination with pozzolans, like silica fume or fly ash, reduce capillary porosity and enhance durability (Chokri et al., 2019; Lim & Tay, 2020). These mixes exhibit reduced water absorption and improved strength due to denser microstructure.

2.9 Microstructure and Pore Distribution

The pore structure of foam concrete is crucial to its water absorption behavior. PKO-based foams tend to form irregular but finer pores compared to synthetic ones (Lim et al., 2021). When combined with SCMs, these pores become less connected, reducing permeability and enhancing resistance to water ingress (Zhou et al., 2017).

2.10 Environmental and Economic Impact

PKO is abundant in tropical countries like Nigeria, Malaysia, and Indonesia. Its use in foam concrete promotes waste valorization and reduces reliance on imported chemicals (Yusof & Zulkifli, 2022). Life-cycle assessments have shown that PKO surfactants reduce environmental impact by approximately 25% compared to synthetic alternatives (Ahmed et al., 2022).

2.11 Research Gaps Identified

Despite promising findings, several gaps remain:

- Lack of long-term durability data beyond 90 days.
- Inconsistency in PKO surfactant preparation and quality grading.
- Limited field-scale performance data.

- Incomplete understanding of environmental leaching and biodegradation.

2.12 Summary of the Literature

Palm Kernel Oil Surfactant represents a green, cost-effective alternative in foam concrete production. When used in hybrid formulations with SCMs and fibers, it can reduce water absorption and maintain acceptable density. Continued research is needed to optimize mix designs and validate performance on a larger scale.

CHAPTER THREE

METHODOLOGY

3.0 INTRODUCTION

To achieve the aim and objectives of this project work. This methodology outlines the steps involved in preparing, testing, and analyzing the water absorption and density of hybrid foam concrete incorporating palm kernel oil (PKO) surfactant and sodium lauryl sulfate as a foaming agent. The study will evaluate both fresh and hardened properties to determine the suitability of PKO-based foam concrete for construction applications.

3.1 MATERIALS AND MIX PROPORTION

The materials comprise of Cement (Portland Limestone Cement), Palm Kernel Oil Surfactant (PKOS), Foaming Agent (Sodium Lauryl Sulfate (SLS)), Water, Sand (fine Aggregate) and Aggregate (Stone Dust)

3.1.1 Materials Selection/Procurement

A. Cement

Portland Lime Cement was used for this research. The cement serves as the primary binder agent for the foam concrete. The PLC was bought from the cement dealer Sokoto cement. Each bag of PLC is 50kg in size and the grade is 42.5R.

B. Palm Kernel Oil Surfactant

Palm kernel oil surfactants are derived from the oil extracted from the seeds of the palm kernel through processes such as polyesterification. PKO-S is obtained from a nearby market around the Ilorin metropolis.

C. Aggregate (Stone Dust & Fine)

Stone dust has been introduced as a hybridized coarse aggregate in the mix. Since, there is no need for coarse aggregate in foam concrete to reduce its weight and density. Stone dust is collected from quarry sites and sieved using a 1.7mm sieve to remove particles. The gradation of the fine aggregate (including fine sand and stone dust) is verified per ASTM C33/C33M standards, ensuring uniformity and suitability for concrete applications. ASTM C33 specifies that fine aggregates should have a well-graded particle size distribution, typically passing a 4.75mm sieve, with a controlled percentage of finer particles to optimize packing and performance.

D. Foam Agent (SLS)

Sodium Lauryl Sulfate obtained from reputable chemical distributors, ensuring high purity (typically ≥98%) and consistency. Suppliers are selected based on proximity to reduce transportation costs and ensure timely delivery.

E. Water

Water is essential for hydration and foam generation. Potable water has been used for mixing and curing, conforming to ASTM C1602. The water used for this work was obtained from the nearby water source at Institute of Technology, Kwara State Polytechnic, Ilorin. The water was free from injurious amount of oil, acid, organic matter, alkali and other deleterious substances

3.1.2 Mix Proportion

The mix will follow a cement-to-sand-to-stone dust ratio of 1:2:4, with a 0.4 water- cement ratio. The PKO surfactant will be introduced in varying proportions to achieve different densities of foam concrete.

3.2 MIXING PROCEDURE

Material Preparation: Weighing the required quantities of cement, sand, stone dust, and water. Prepare the SLS foaming agent solution separately.

Mixing Process: Dry mix cement, sand, and stone dust thoroughly according to the mixing ratio by weight. Gradually add water and mix for 3–5 minutes. Introduce SLS foaming agent and continue mixing to ensure even foam distribution.

Casting & Curing: Pour the fresh mix into molds for testing (cubes, cylinders, or prisms). Allow the samples to set for 24 hours before demolding. Cure the specimens in water for 7, 14, and 28 days for strength and absorption testing.

3.3 Preparation of the Foaming Agent

Aim: To get the foam so for the concrete to be light in weight and porosity

Materials: bucket, water and the foaming agent (SLS)

Procedure:

3.3.1 Pour the quantity of water needed into the bucket

3.3.2 Pour in the (SLS) into the water

3.3.3 Stir even until the foaming is desire

3.4 LABORATORY TEST AND MEASUREMENTS

Laboratory tests are essential procedures carried out under controlled conditions to evaluate the physical, mechanical, and fresh properties of construction materials. In the context of this study, tests such as workability and density assessments were conducted to determine how palm kernel oil surfactant (PKOS) influences the performance of hybrid foam concrete. These tests help ensure consistency, validate improvements in mix quality, and provide reliable data for predicting material behavior in real-world construction scenarios.

3.5.1 Fresh Properties (Workability & Density Tests)

Workability is a vital aspect of fresh foam concrete as it determines how easily the mix can be placed, compacted, and finished. Fresh density, on the other hand, reflects the compactness and stability of the concrete before setting

1 Slump Test

Slump test is a method used to determine the consistency or workability of a fresh concrete. The consistency indicates how much water has been used in the mix. Consistency is very closely related to workability that describes the state of fresh concrete. It indicates the degree of wetness and refers to the ease with which the concrete flows. Concrete slump test is popular due to the simplicity of apparatus used and simple procedure. The test is very simple. That is why it often allows a wide variability in the manner that the test is performed and able to be conducted on site.

The application of slump test is used to ensure the uniformity for different batches of similar concrete under field conditions and to ascertain the effects of plasticizers on their introduction. This test is very useful on site as a check on the day-to-day or hour-to- hour variation in the materials being fed into the mixer. An increase in slump might indicate that the moisture content of aggregate has unexpectedly increased. Other cause would be a change in the grading of the aggregate, such as deficiency of sand. Too high or too low a slump gives immediate warning and enables the mixer operator to remedy the situation.

2 Fresh Density Test (Wet)

The purpose of the density test is to control the quality of the fresh mixed concrete for test. The density of concrete is defined as the measure of the compactness of concrete, expressed as its mass per unit volume. A known volume of fresh concrete is weighed to calculate density (kg/m³).

Formula:

Density *= Mass of Concrete / Volume of Container*

3.5.2 Hardened Properties (Density & Water Absorption Tests)

1 Hardened Density Test (Dry)

Density of hardened concrete is critical to the performance of the structure. Consistency in the density of the concrete at all stages indicates consistency in all phases of concrete operations. These tests are mainly conducted in order to maintain control over the batching and mixing of the concrete making sure that the concrete produce meets with the specific requirements. It can also be used to indicate segregation, non-uniform consolidation, and several other problems. So we oven-dried concrete samples which we weighed and divided by their volume. Higher density indicates stronger concrete, while lower density improves insulation.

2 Water Absorption Tests

We measure total porosity by comparing dry weight vs. saturated weight. The apparatus used for this test were: balance, pan for drying, Water-tight container, pan for saturated drying and duster.

Formula:

$$\textbf{Water Absorption (\%)} = \frac{(\text{Weight of saturation sample} - \text{Weight of dry sample})}{\text{Weight dry sample}} \times 100$$

3.6. DATA ANALYSIS

Comparing the results across different PKO surfactant dosages. Assess trends in density and water absorption for different mix compositions, and evaluating the optimum PKO concentration for balancing strength, durability, and lightweight properties.

3.7. SELECTED FIGURE FROM THE PRACTICAL WORKS

Fig 3.2: Curing of the cubes

Fig 3.4: Weighed Materials before mixing

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 PROPERTIES OF MATERIALS

The table below shows the properties of materials used in this research project. Table 4.1 Properties of Materials Used

Materials	**Density (Kg/m^3)**
Stone Dust	1800
Cement	1440
SLS	400
Water	1000
PKO	940

4.1 FRESH PROPERTIES

4.1.1. Workability

The slump test was conducted to evaluate the workability of the fresh concrete mix. The values indicate the ease with which the mix flows, measured using a standard slump cone.

Table 4.2. Workability of Hybrid Foam Concrete

% of P.K.O.	Slump Value (mm)	Workability
0	120	Very High Flowable
1.5	110	High Flowable
3	90	Low Flowable

From table 4.2 it was observed that as PKO concentration increases, slump values decrease, indicating reduced workability likely due to air entrainment and altered mix consistency. The recorded slump value shows that the lower the percentage of P.K.O the higher it flowable, with 0% give 120mm and 3% give 90mm. Which is within the range of 90mm – 120mm. Therefore, the results of the slump are a partially shear.

4.1.2. Fresh Density of The Foam Concrete

Fresh density refers to the mass per unit volume of the concrete immediately after mixing, including entrained air. It was measured in kgm^{-3} using the weight-to-volume method.

Table 4.3. Fresh Density of The Hybrid Foam Concrete

Sample Id	% of P.K.O.	Mass m1 (g)		Volume V1 (m^3)	Density P = m1/V1 (kgm^{-3})
A	0	6417	6482	0.003375	1921
		6547			
B	1.5	6864	7058	0.003375	2091
		7252			
C	3.0	7514	7424	0.003375	2200
		7333			

The result from the table 4.3 indicate that density increases with higher PKO concentrations, showing the effectiveness of PKO as a lightweight surfactant.

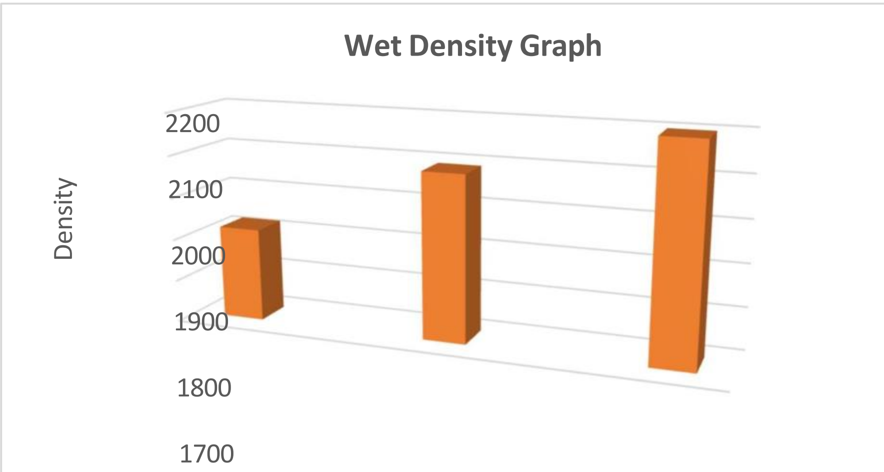

Fig 4.1: Fresh Density vs Percentage of Palm Kernel Oil (PKO)

4.2 DRY PROPERTIES

4.2.1. Water Absorption

Water absorption was measured as the percentage increase in specimen weight after 24- hour immersion. It reflects the porosity of the hardened concrete and affects durability.

Table 4.4. Water Absorption of Hybrid Foam Concrete

Sample ID	% of P.K.O.	Initial Dry Weight m_1 (g)	Final Weight (24hrs) m_2 (g)	Value of Water Absorption W_o	% of W_o
A	0	6172	6310	0.0224	2.24
B	1.5	6758	6887	0.0191	1.91
C	3.0	7159	7295	0.0189	1.89

Formula: Water Absorption (%) = ((Wet - Dry) / Dry) × 100

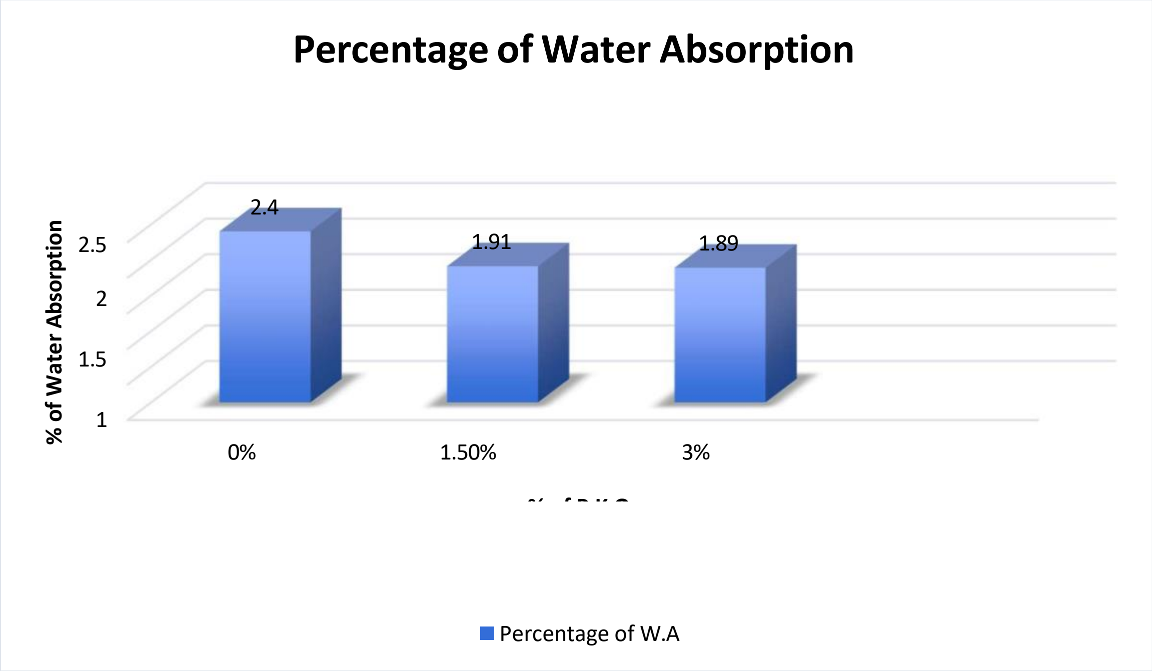

Fig 4.2: Water Absorption vs Percentage of Palm Kernel Oil (PKO)

The percentage of water absorption decrease with PKO, reflecting decrease in porosity. Optimal performance was observed around 1.5%–3.0% PKO concentration.

4.2.2. Dry Density

Dry density was measured after 28 days of curing to assess the hardened structure of the concrete. Lower dry density indicates more entrained air and a lighter concrete.

Table 4.4. Dry Density of Hybrid Foam Concrete

Sample ID	% of P.K.O.	Mass m1 (g)		Volume V1 (m^3)	Density P = m1/V1 (kgm^{-3})
A	0	6117	6172	0.003375	1829
		6227			
B	1.5	6664	6758	0.003375	2002
		6852			
C	3.0	7134	7159	0.003375	2121
		7183			

The increase in PKO reduces the final density of the concrete which show in the fig 4.3 below. However, excessive reduction may compromise strength.

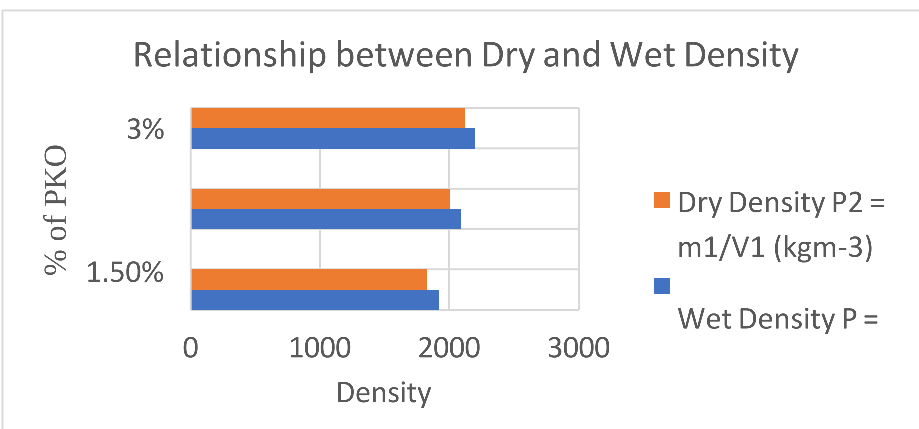

Fig 4.3: Dry Density vs Percentage of Palm Kernel Oil (PKO)

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

1. Palm kernel oil-based surfactant (PKO-S) improved the workability of hybrid foam concrete, with the best slump value of 120mm observed at 0% PKO, and a slight reduction as PKO increased, indicating altered flow behavior.

2. Dry density dropped with increasing PKO-S content, reaching 1829 kg/m³ at 3%, proving its suitability for producing lightweight foam concrete.

3. PKO-S reduced water absorption from 2.24% to 1.89%, confirming its effectiveness in minimizing porosity and enhancing the concrete's resistance to moisture penetration.

4. Samples with PKO-S performed better in both water absorption and density than those without, confirming the value of PKO in improving physical properties

5.2. RECOMMENDATIONS

i. **Optimal PKOS Dosage**: Based on experimental results, a PKOS concentration range of 1.5–3.0% is recommended for achieving balanced properties of strength, durability, and lightweight construction.

ii. **Further Research:** Additional studies should explore long-term durability, structural integrity, and resistance to environmental factors such as temperature variations and chemical exposure.

iii. **Practical Applications:** Field applications should be conducted to assess the real- world performance of PKOS-based foam concrete in construction, particularly for insulation, partitioning, and lightweight structural elements.

iv. **Economic Feasibility Analysis:** A comparative cost-benefit assessment should be conducted to evaluate the affordability and scalability of PKOS-enhanced foam concrete compared to conventional foaming agents.

v. **Comparative Analysis:** Future research should compare PKOS-based foam concrete with other eco-friendly foaming agents to determine its superiority in sustainability and cost-effectiveness.

vi. **Regulatory Considerations:** Standardization efforts should be initiated to establish industry guidelines for PKOS-based foam concrete, ensuring its widespread adoption in sustainable building practices.

vii. **Innovation in Hybrid Mixes:** Researchers can explore combining PKOS with other natural surfactants or supplementary materials like recycled aggregates to further optimize foam concrete properties.

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