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OPTIMIZATION OF HYBRID FOAM CONCRETE MIX DESIGN USING PALM KERNEL OIL BASED SURFACTANT AND LATERITE SOIL

BY

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BEING RESEARCHED AND SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING, INSTITUTE OF TECHNOLOGY, KWARA STATE POLYTECHNIC, ILORIN

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DECLARATION

I hereby declare that this project work titled OPTIMIZATION OF HYBRID FOAM CONCRETE MIX DESIGN USING PALM KERNEL OIL BASED SURFACTANT AND LATERITE SOIL is a work done by me, SHUAIB ABDULWASIU OMOLABI with matric number, HND/23/CEC/FT/0098 of the Department of Civil Engineering, Institute of Technology, Kwara State Polytechnic, Ilorin.

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Signature Date

CERTIFICATION

This is to certify that this research study was conducted by **SHUAIB ABDULWASIU OMOLABI (HND/23/CEC/FT/0098)** and had been read and approved as meeting the requirement for the award of Higher National Diploma (HND) in Civil Engineering of the Department of Civil Engineering, Institute of Technology, Kwara State Polytechnic, Ilorin

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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 and to my late Mom, Mrs. Selimot Abdulsalam.

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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TABLE OF CONTENTS

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This study aims to optimize the mix design of hybrid foam concrete by incorporating palm kernel oil-based surfactant (PKOS) and lateritic soil (LS) to enhance its mechanical and physical properties. Foam concrete is valued for its lightweight, thermal insulation, and fire resistance properties, but its mechanical strength often requires improvement. The research investigates the effects of PKOS and LS on foam stability, density, compressive strength, and water absorption. Laboratory experiments were conducted using varying concentrations of PKOS (0%, 1.5%, and 3.0%) and LS as a partial replacement for fine aggregates in a 1:2 mix ratio (60% stone dust and 40% laterite soil). The results revealed that increasing PKOS concentrations led to higher densities, with the 3.0% PKOS mix achieving the highest density at 28 days. However, compressive strength varied, with the control mix (0% PKOS) exhibiting the highest strength at 28 days, while the 1.5% and 3.0% PKOS mixes showed comparable strengths. The study highlights the potential of PKOS and LS in improving foam concrete properties while addressing sustainability and cost-effectiveness. The findings contribute to the development of eco-friendly construction materials, particularly in regions abundant in palm kernel oil and lateritic soil, and provide insights for further optimization of hybrid foam concrete mixes.

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Concrete is a relatively heavy building material; therefore, many experiments have been conducted throughout the twentieth century to decrease its weight without impairing other properties. During the 1920s and 1930s, many different types of lightweight concrete were developed, e.g., Durisol, Siporex, Argex, and Ytong. Probably the most famous and first type of autoclaved gas concrete was Ytong. It was invented by the Swedish architect, Johan Axel Eriksson, assistant professor at the Royal Institute of Technology in Stockholm. In the early 1920s, Eriksson experimented with different samples of gas concrete and put the mixtures in an autoclave to speed up the curing process. In November 1929, the industrial production of Ytong blocks began. The name combines the y of Yxhult, where the first Swedish factory was located, and the end of betong, the Swedish word for concrete. The material was viral in Sweden from 1935 onward, with a true breakthrough immediately after World War II, when it became one of the most important building materials in the country. Also, the manufacturing process was exported to other countries such as Norway, Germany, the UK, Spain, Poland, Israel, Canada, Belgium, and even Japan. The autoclaved gas concrete Siporex was developed in Sweden in 1935. The

LWAC, Argex, was first produced in Denmark in 1939 under the international brand Leca. Starting with an annual production in Copenhagen of 20,000 m3, the total output throughout Europe had increased by 1972 to nearly 6 million m3 per year (Hedjazi S. 2019).

Concrete is a fundamental construction material, valued for its compressive strength, durability, and versatility. However, traditional concrete can be heavy and rigid, limiting its applications in areas that require lighter materials. Foam concrete, also known as cellular lightweight concrete, has emerged as a viable solution to address these limitations. This form of lightweight concrete is produced by introducing a foaming agent into the cementitious mix, which generates a cellular structure with air voids. Foam concrete is distinguished by its low density, thermal and acoustic insulation properties, flow ability, and reduced dead load, making it ideal for non-structural elements, void filling, and load-bearing walls under certain conditions (Kearsley & Wainwright, 2001; Jones & McCarthy, 2005).

Foamed concrete is a new-generation material and the future technology of modern construction. This product performs better than other concretes, particularly in strength application areas. The foamed concrete is produced with the aid of a foam injection machine and foam generator. The foaming agents are commonly alcohol-based, animal fat-based, and vegetable oil-based. In the current scenario, people are more concerned with the performance of vegetable-based surfactants against chemical-based agents. However, vegetable oil cannot produce a long-term stable chemical process, and this limitation offers a window for future research on the material properties. (Shah et al.2021).

Foam Concrete (FC) contains more pores than traditional lightweight concrete. Therefore, FC can be considered a supplementary structural material used to reduce noise and isolate areas. FC has a stronger matrix structure than lightweight concrete. The porosity of foam and lightweight concretes reduces as the density of the material increases. The porosity of lightweight concrete is highly affected by the aggregates' pore features, and that of FC is affected by the pore structure of the matrix. Furthermore, when the density of FC and lightweight concrete is at the same level, FC contains greater porosity (Calis. G. 2021).

Concrete is a crucial material in the construction industry due to its compressive strength, versatility, and durability. Despite its widespread application, conventional concrete's significant weight can limit its suitability in certain structural scenarios, particularly in projects where weight reduction is critical. Foam concrete has emerged as a solution to this problem, providing a lightweight alternative that maintains essential structural characteristics. Foam concrete achieves its reduced density through the incorporation of air voids, which are created by adding a foaming agent into the cementitious mix. These voids lead to a cellular structure that improves the concrete's insulation properties, enhances workability, and reduces the overall dead load of a structure (Kearsley & Wainwright, 2001; Jones & McCarthy, 2005).

Foam concrete's properties, such as compressive strength and thermal insulation, are highly influenced by the choice and quantity of foaming agent used. Traditional foaming agents are usually synthetic and derived from petrochemical sources, which can be costly and environmentally harmful. The search for sustainable alternatives has led researchers to explore natural surfactants that can achieve similar performance at lower costs and with reduced ecological impact. Among these alternatives, palm kernel oil-based surfactant (PKOS) and lateritic soil (LS) have shown promise for use in foam concrete, particularly in regions where these materials are locally available (Amran et al., 2015; Narayanan & Ramamurthy, 2000).

It has been shown that foam concrete's compressive strength is directly related to its dry density; as the density decreases, the compressive strength also decreases. The foam volume is the most notable parameter controlling the compressive strength of foam concretes. Increasing the foam volume promotes air entrained in concrete, reducing compressive strength. (Hedjazi S. 2019).

The compressive strength and density of foam concrete are influenced by the type and quantity of foaming agent used. Traditional foaming agents, usually synthetic, provide stability but are often costly and have environmental drawbacks. Therefore, natural and hybrid foaming agents are gaining traction as sustainable alternatives. In particular, palm kernel oil-based surfactant (PKOS) and lateritic soil (LS) have shown the potential to provide stability and strength while reducing costs and environmental impact (Amran et al., 2015; Narayanan & Ramamurthy, 2000). The use of these natural surfactants aligns with the objectives of sustainable development, as they are biodegradable, less toxic, and locally available in tropical regions where palm oil is abundant.

PKOS, derived from the widely cultivated oil palm tree, has been identified as a biodegradable, eco-friendly surfactant that can stabilize foam and contribute to consistent air void distribution in foam concrete. Research indicates that PKOS improves the mechanical properties of foam concrete, making it a viable alternative to synthetic surfactants in terms of both performance and environmental impact (Jones & McCarthy, 2005). Similarly, LS is rich in iron and aluminum oxides, enhancing foam's stability and cohesiveness in the concrete mix. This leads to improved compressive strength and air entrainment, further enhancing the foam concrete's physical properties (Kearsley & Wainwright, 2001).

Palm kernel oil-based surfactant (PKOS) is derived from the oil palm tree, which is predominantly cultivated in tropical regions. As a biodegradable and renewable resource, PKOS aligns with sustainable construction practices by offering an eco-friendly alternative to synthetic foaming agents. PKOS's surfactant properties make it suitable for stabilizing foam within the concrete matrix, contributing to a uniform distribution of air voids. This leads to enhanced insulation properties and potentially improved compressive strength in foam concrete applications. Additionally, PKOS production and use reduce reliance on synthetic chemicals and align with local resource utilization, particularly in regions where palm oil is abundantly available (Jones & McCarthy, 2005).

Laterite Soil (LS), is another natural material that shows potential in foam concrete applications. Lateritic soils, characterized by their high iron and aluminum oxide content, are common in tropical and subtropical regions. These soils possess natural stabilizing properties, which can contribute to foam stability and durability when incorporated as a surfactant in foam concrete. LS enhances the cohesiveness of the foam matrix and can improve the mechanical properties of foam concrete, including compressive strength and durability (Kearsley & Wainwright, 2001).

When used together, PKOS and LS create a hybrid surfactant mix that combines the stabilizing properties of both agents. The hybridization approach aims to achieve an optimal balance between strength and density, which is essential for foam concrete applications requiring structural stability with reduced weight. This approach not only improves the mechanical properties of foam concrete but also reduces the environmental footprint by minimizing reliance on synthetic chemicals (Nambiar & Ramamurthy, 2006).

Optimizing the proportions of PKOS and LS in foam concrete is crucial to achieving a mix that maximizes performance. Various mix proportions and ratios will impact foam stability, air void distribution, density, and mechanical properties. Optimization techniques, such as response surface methodology (RSM), offer a systematic way to evaluate the interactions between different variables and identify the ideal mix design for desired outcomes. An optimized hybrid foam concrete mix could potentially reduce material costs, enhance workability, and maintain structural integrity, making it suitable for a wider range of applications in construction (Nambiar & Ramamurthy, 2006).

The adoption of natural surfactant like PKOS in foam concrete production aligns with sustainable development goals by reducing the environmental impact of construction materials. Synthetic surfactants, although effective, often have a high carbon footprint due to their petrochemical origins and non-biodegradable nature. Conversely, PKOS and LS are renewable resources that are both biodegradable and locally available, reducing the carbon footprint associated with material transportation and disposal. This approach not only promotes the conservation of non-renewable resources but also contributes to reducing greenhouse gas emissions, aligning with global sustainability targets in the construction sector (Narayanan & Ramamurthy, 2000).

The expected outcome in a foam concrete formulation is not only lightweight concrete but also a cost-effective and sustainable concrete product. Such a product would have significant applications in lightweight construction and could serve as a sustainable alternative to traditional foaming agents in the industry. Additionally, optimizing the use of PKOS and LS aligns with local resource utilization strategies in regions where these materials are plentiful, offering a scalable solution that addresses both environmental and economic challenges in construction (Amran et al., 2015).

1.2 Problem statements

The current foam concrete mix designs frequently do not maximize the potential of locally available materials and sustainable additives. This oversight not only increases costs but also contributes to environmental degradation. Despite the promising potential of PKOS and LS as an alternative in the mixed design of foam concrete, there is limited research on their combined effects. Most studies have focused on synthetic foaming agents or individual natural surfactants, leaving a gap in understanding the optimal hybridization of PKOS and LS. The key challenge is to determine the ideal proportions and conditions for PKOS and LS that yield a foam concrete mix with the desired mechanical properties and minimal environmental impact.

1.3 Justification of the study

This study is vital for advancing sustainable construction practices by investigating the efficacy of local materials and bio-based surfactants. Optimizing foam concrete mix designs can lead to significant improvements in material properties, potentially transforming the construction landscape, especially in regions where palm oil production and lateritic soil are prevalent (Papánová & Prišč, 2024). The research findings could provide practical solutions for reducing reliance on traditional materials, thereby lowering construction costs and environmental impacts.

Also, it's crucial to promote sustainable construction practices by exploring local materials and bio-based additives. By optimizing the foam concrete mix design, we can enhance material properties while reducing waste and environmental degradation. The findings can contribute significantly to the field of civil engineering, particularly in regions where lateritic soil is abundant and palm oil production is a major industry.

1.4 Aim of the study

This study aims to optimize the mix design of hybrid foam concrete using palm kernel oil-based surfactant and lateritic soil.

1.5 Objective of the project

The objective of this research is as follows:

1) Investigation into the effects of palm kernel oil-based surfactants and lateritic soil on the compressive strength of foam concrete.

2) Investigation into the effects of palm kernel oil-based surfactants and lateritic soil on the density of foam concrete.
3) Analyzing how varying concentrations of the surfactant influence the water absorption of hybrid foam concrete.
4) To examine the optimal concentration of hybrid foam concrete using palm oil-based surfactants and lateritic soil.

1.6 Scope and limitations of the study

This study focuses on the formulation and testing of foam concrete mixes incorporating palm kernel oil-based surfactant and lateritic soil. Laboratory experiments were conducted to assess mechanical properties such as compressive strength, as well as workability and thermal insulation characteristics. This research is limited to specific proportions of surfactant and lateritic soil, ensuring that the results are applicable to standard construction practices while considering local material availability. While the study aims to provide comprehensive insights into the performance of hybrid foam concrete, limitations may include:

1. **Geographic constraints:** The availability of palm kernel oil and lateritic soil may vary by region, affecting the generalizability of the findings.

2. **Experimental conditions:** The laboratory environment may not fully replicate real-world conditions, potentially influencing the performance of the developed concrete.
3. **Economic analysis:** While the study will provide a preliminary economic assessment, a more detailed life-cycle cost analysis may be needed to fully understand the financial implications of using these materials in large-scale construction.

CHAPTER TWO

LITERATURE REVIEW

2.1 Foam Concrete

Foam concrete is either a cement paste or mortar, classified as lightweight concrete, in which air voids are entrapped in mortar by a suitable foaming agent. It possesses high flowability, low self-weight, minimal consumption of aggregate, controlled low strength, and excellent thermal insulation properties. By proper control of the dosage of foam, a wide range of densities (1600– 400 kg/m3) of foamed concrete can be obtained for application to structural, partition, insulation, and filling grades. Although the material was first patented in 1923. Recently, (Jones and McCarthy, 2005) have reviewed the history of the use of foam concrete, its constituent materials, its properties, and construction applications including some projects carried out worldwide. The functional properties like fire resistance, thermal conductivity, and acoustical properties are also included in these reviews, while the data on fresh state properties, durability, and air-void system of foam concrete are rather limited. The production of stable foam concrete mix depends on many factors viz., selection of foaming agent, method of foam preparation and addition for uniform air-void distribution, material section and mixture design strategies, production of foam concrete, and performance concerning the fresh and hardened state are of greater significance. With the above aspects in view, this paper classifies the studies on foam concrete related to its constituent materials, mix proportioning, production fresh state, and hardened properties. (K. Ramamurthy et. al 2008)

Foam concrete, also known as cellular or aerated lightweight concrete, has emerged as a versatile building material, noted for its low density, high insulation properties, and ease of production. With a structure composed of air-filled voids within a cementitious matrix, foam concrete achieves a lightweight profile that can be advantageous for applications where reduced structural load and energy efficiency are paramount. Originally developed in the early 20th century, foam concrete has gained substantial interest in recent decades, particularly with the push toward sustainable and resource-efficient construction practices (Jones & McCarthy, 2005).

The cellular structure of foam concrete is created by introducing stable foams, typically generated by foaming agents, into the concrete mix. This results in a lightweight material that offers enhanced thermal insulation, sound absorption, and workability. The density of foam concrete can be adjusted to suit specific applications, ranging from high-density structural components to low-density insulation panels, depending on the foam volume and mix proportions (Kearsley & Wainwright, 2001)

The relevant mechanical research on foamed concrete materials is mainly focused on static properties. A high-performance foamed concrete mixture and proposed prediction models for the mechanical properties by regression analysis were developed on a large amount of test data. Kearsley and Wainwright (2001) carried out many experiments to obtain an optimized mixing ratio of fly ash and cement. They studied the effect of the porosity and fly ash content on the compressive strength of foamed concrete. The effects of three different foaming agents on the mechanical properties and pore structure of foamed concrete with alkali-activated slag cement were also investigated. A damage mechanics model that described the nonlinear mechanical behavior of foamed concrete by performing a series of uniaxial compression tests considering the temperatures and strain rates was established. A constitutive model of damage to forecast the nonlinear responses based on the mechanical behavior of foamed concrete under uniaxial compression was also proposed. In addition, a yield criterion considering hydrostatic tension was put forward to describe the multiaxial mechanical properties and was verified by a comparison with the results of tri-axial experiments.

Furthermore, a sensitivity analysis was conducted to investigate the effects of the density and the water-to-cement and sand-to-cement ratios on the compressive strength. A prediction for the compressive strength based on the fractal dimension of the porous structure in foamed concrete was proposed. A variety of uniaxial compressive tests for foamed concrete specimens with various height-to-diameter ratios and densities to obtain the relations between the mechanical characteristics and height-to-diameter ratios were designed (Feng. S. 2020).

2.1.1 Properties of foam concrete

Foam concrete is characterized by its unique combination of lightweight composition and versatility in thermal, acoustic, and mechanical properties. This composition stems from a cement-based matrix mixed with a stable foam that introduces numerous air voids. These air-filled voids, ranging from a few micrometers to several millimeters in diameter, contribute to foam concrete's distinct characteristics. This section provides an in-depth look at the essential properties of foam concrete, highlighting factors that influence each attribute.

Mechanical Properties

Mechanical properties are considered the most important factor in measuring the applicability of foamed concrete in the hardened state. Foam concrete's mechanical properties such as compressive strength, flexural strength, and modulus of elasticity are central to its performance in structural and semi-structural applications. The material's behavior under load is influenced by its cellular structure, density, and composition. Typically, foam concrete has lower mechanical strength than conventional concrete due to its high air content, but optimization through mix design and reinforcement enables its application in various structural roles.

a) Compressive Strength: Compressive strength is one of the most important mechanical properties of foam concrete, and it is often determined by its suitability for structural and load-bearing applications. The compressive strength of foam concrete generally ranges from 1 MPa to over 30 MPa, depending on its density and mix composition (Jones & McCarthy, 2005). Factors influencing compressive strength include:

   i. Density: Foam concrete's compressive strength increases with density, as higher densities contain less foam, resulting in a denser, more compact matrix. Low-density foam concrete (300–800 kg/m³) typically achieves compressive strengths below 5 MPa, while high-density mixes (over 1,200 kg/m³) can reach 30 MPa or more.

   ii. Foam Content and Quality: A higher foam content typically decreases compressive strength due to the increased volume of air voids. The stability of the foam, influenced by the foaming agent and mixing technique, also impacts strength.

   iii. Cement Content and Additives: Increasing cement content generally improves compressive strength. Additives like fly ash, silica fume, and ground granulated blast furnace slag (GGBS) can improve strength by densifying the matrix and reducing porosity (Kearsley & Wainwright, 2001).

iv. Curing Conditions: Proper curing enhances compressive strength by preventing rapid moisture loss, which can lead to shrinkage and reduced strength. Moist curing or steam curing may be used to achieve higher strengths.

Experimentally, it is observed that compressive strength has a direct relationship with density where a reduction in density exponentially and adversely affects the compressive strength. As can be seen, the dry densities in previous studies ranged between 280 and 1800 kg/m3 by which a remarkable change in the compressive strength was observed. In general, compressive strength depends on different parameters such as the rate of foam agent, water/cement ratio, sand particle type, the curing method, cement–sand ratio, and characteristics of additional ingredients and their distribution.

One of the major controlling factors in the compressive strength of the mix is the volume/density of the foaming agent by which the amount of air voids in the hardened foamed concrete varies. For example, when the plastic densities of foamed concrete were 1800 kg/m3 and 280 kg/m3, the associated compressive strength at 28 days was 43 MPa and 0.6 MPa, respectively. The excessive addition of foam agents depleted the compressive strength because the higher volume of foam agents commonly created air voids, resulting in a lower density.

The water/cement ratio is another controlling factor that influences the compressive strength of the foamed concrete. An appropriate water content enhances the consistency and stability of the mix and reduces the large-size foam bubbles, which increases the compressive strength.

The curing method is another key factor that influences the compressive strength of foamed concrete. According to (ASTM C 796), lightweight and cellular concrete samples used to conduct compression tests should be cured in a moist room with 100% relative humidity (RH) for at least three days before testing. The samples should be taken out from the curing room and oven-dried at 60 _C for 72 h. it was reported that to obtain the desired compressive strength, the samples should be cured in normal moist air for one day and then in steam where the temperature should increase to 20 _C/ h to preserve at 65 _C for 4 h and then cooled in the air (Amran, Y. H. M., et al. 2015)

Flexural Strength: The ratio of flexural strength to compressive strength of cellular concrete is in the range of 0.25–0.35. Splitting tensile strengths of foam concrete are lower than those of equivalent normal weight and lightweight aggregate concrete with higher values observed for mixes with sand than those with fly ash. This increase is attributed to the improved shear capacity between the sand particle and the paste phase. The use of

Polypropylene fibers has been reported to enhance the performance concerning tensile and flexural strength of foam concrete, provided it does not affect fresh concrete behavior and self-compaction (K. Ramamurthy, 2009). The factors that influence the flexural strength of foam concrete are as follows:

i) **Density and cement content**: Flexural strength in foam concrete is closely tied to density. Higher-density foam concrete has a more compact matrix with fewer and smaller air voids, which allows it to resist bending forces more effectively. Low-density foam concrete typically has a flexural strength of less than 1 MPa, while high-density mixes can reach flexural strengths between 3 and 5 MPa (Kearsley & Wainwright, 2001).

ii) **Type and quality of foaming agent**: The stability and uniformity of the foam play a vital role in flexural strength. Stable foams produce a more consistent air-void structure within the concrete, which helps evenly distribute stress across the material. The type of foaming agent used impacts foam stability; natural surfactants like palm kernel oil-based and lateritic surfactants can create more uniform and stable foams, which enhances flexural strength by ensuring fewer void clusters and more even stress distribution.

The use of hybrid natural surfactants, offers new possibilities for improving foam stability and flexural strength. These surfactants provide more stable foams with uniform air-void distribution, which prevents clustering and creates a matrix capable of distributing flexural stress more evenly. Additionally, natural surfactants can reduce production costs and environmental impact, promoting sustainable development in foam concrete applications (Zhang et al., 2024).

Dry density, kg/m^3	Compressive strength, MPa	Elastic modulus, GPa	Thermal conductivity, W/m. K
400	1	1	0,1
600	1,5	1,5	0,11
800	2	2,5	0,2
1000	5	3	0,3
1200	10	4	0,4
1400	15	6	0,55
1600	25	12	0,65

Table 2.1. Typical Properties of Foamed Concrete

2.1.2. Applications

The application of foam concrete (FC) in construction is expanding, driven by the demand for lightweight materials with good thermal insulation properties. Foam concrete is typically used for non-structural applications like partition walls, filling voids, and thermal insulation, but its range of uses has grown due to its versatility and adaptability. By incorporating sustainable additives like palm kernel oil-based surfactants and locally available lateritic soil, foam concrete's environmental impact, performance, and cost-effectiveness can be significantly enhanced. This section explores the potential applications of foam concrete using PKO-based surfactants and lateritic soil, highlighting key findings and real-world uses in the construction industry.

Foam concrete has found widespread applications in various construction sectors due to its unique combination of lightweight properties, durability, and thermal insulation capabilities. One of its primary uses is in sound and thermal insulation of floors, where its porous structure effectively dampens noise and provides energy-efficient solutions for residential and commercial buildings (Jones & McCarthy, 2005).

Foam concrete FC has been used extensively in insulating materials for roofs, floors, and walls. It is also utilized in road sub-bases, lightweight precast elements, and void filling in geotechnical applications. According to (Zhang et al., 2024), foam concrete is particularly effective for energy-saving construction because it helps maintain temperature stability inside buildings, reducing heating and cooling costs.

In roof insulation and thermal protection, foam concrete offers superior performance in reducing heat transfer, particularly in tropical and temperate regions. Studies have shown that structures incorporating foam concrete roofing require significantly lower energy consumption for cooling and heating compared to traditional concrete roofs (Amran et al., 2015).

Another important application is in well and cavity backfilling, where its self-compacting and lightweight nature makes it an ideal material for filling voids, trenches, and underground spaces without exerting excessive pressure on surrounding structures. Research suggests that foam concrete reduces settlement issues and enhances structural stability in underground works (Jalal et al., 2017).

Foam concrete is also widely used in masonry grouting and wall panels, providing an eco-friendly alternative to conventional masonry units. It improves structural integrity while reducing the overall dead weight of buildings. Moreover, monolithic low-rise and individual house construction projects benefit significantly from the material's ease of handling and rapid placement, leading to faster construction times and lower labor costs (Ikponmwosa et al., 2017).

Infrastructure projects, such as road sub-bases and bridge abutments, increasingly incorporate foam concrete due to its resistance to freeze-thaw cycles and excellent load distribution characteristics. Studies indicate that roadbeds constructed with foam concrete exhibit enhanced longevity and reduced maintenance requirements (Hazlin et al., 2017). Additionally, ground stabilization efforts benefit from foam concrete's ability to reinforce weak soil structures and mitigate risks associated with land subsidence and erosion (Kearsley & Wainwright, 2001).

2.1.3. *Thermal insulation*

The insulating properties of foam concrete make it an ideal material for constructing green buildings. In cold climates, it acts as an insulating barrier, reducing heat loss, while in hot climates, it can keep buildings cooler by limiting heat transfer from outside. It was demonstrated that foam concrete made with certain additives can achieve a thermal conductivity as low as 0.12 W/m·K, making it a highly effective insulating material (Shi et al., 2024).

Foam concrete is well known for its relatively low thermal conductivity, usually 10–50% of that of normal dense concrete, depending on the designed material density and composition. This low thermal conductivity brings good thermal insulation, and usually energy efficiency in operation (Zhang, Z, et al., 2015). Different foamed concrete's strength varies before and after exposure to temperatures higher than usual. While there is a slight increase in compressive strength before reaching 400°C, the strength gradually decreases as the temperature rises between 400°C to 800°C. The specimen (ES0) The experimental findings revealed that the compressive strength of FC undergoes a slight increase up to a temperature of 400 °C, reaching a peak of 6.1 MPa from an initial value of 5.7 MPa. However, the compressive strength decreases continuously beyond this point, reaching a minimum of 2.9 MPa at 800 °C. The fire protection classification of the FC is by the national class A standard, which makes it suitable for insulation purposes in buildings. Moreover, alkali-activated FC exhibits superior mechanical properties at temperatures under 400 °C compared to other lightweight external wall insulation materials (Mohamed, A, M, et al., 2024).

In another study by (Jones & McCarthy, 2005) it was shown that the thermal conductivity ranges between 0.23 and 0.42 W/mK at dry densities of 1000 and 1200 kg/m3. Besides, the moderate filling of porous mortar with polystyrene granules can produce foamed concrete with a density range of 200-650 kg/m3 with a thermal conductivity of 0.06–0.16 W/mK. It is specified that with each 100 kg/m3 reduction of density, the thermal insulation will drop by 0.04 W/mK of the total thermal insulation of foamed concrete. In practice, foamed concrete slabs demonstrate a superior thermal insulation behavior enhanced with minimized torpidity and increased strength. Also, another study on wall brick masonry revealed that using foamed concrete with a density of 800 kg/m3 in the inner leaf of the wall increased the thermal insulation by up to 23% compared to normal concrete. Some studies showed that the degree of thermal insulation in foamed concrete depends on the mixture composition such as aggregate type and mineral admixtures. Previously, it was reported that the inclusion of lightweight aggregates in foamed concrete was beneficial in decreasing the level of thermal conductivity. For example, foamed concrete with a dry density of 1000 kg/m3 using lightweight aggregate obtained a thermal conductivity 1/6 of the value of typical cement–sand mortar (Amran et al., 2015).

2.2 Palm Kernel Oil-Based Surfactants In Concrete Mixes

Surface active substances or surfactants are amphiphilic compounds having a lyophilic, in particular hydrophilic, part (polar group) and a lyophobic, in particular hydrophobic, part (often hydrocarbon chain). The amphiphilic structure of surfactants is responsible for their tendency to concentrate at interfaces and to aggregate in solutions into various supramolecular structures, such as micelles and bilayers. According to the nature of the polar group, surfactants can be classified into nonionic and ionic, which may be of anionic, cationic, and amphoteric or zwitterion nature.

Surfactants are important ingredients in a great number of formulations and processes. Practically any human activity deals with surfactants. So, the weight of surfactants in present-day detergent products accounts for around 15-25 % of the total production. Their world production approaches 9 million tons plus the same number of soaps, and about half of the quantity is the share of West Europe and North America.

Palm kernel oil-based surfactants are derived from the oil extracted from the seeds of the palm kernel. These natural surfactants are both effective and eco-friendly compared to conventional synthetic surfactants (Pletnev. M.Y. 2001)

The shift toward sustainable construction materials has led to research into plant-based surfactants, which can serve as eco-friendly alternatives to synthetic agents. Palm kernel oil, a natural and renewable resource, has demonstrated potential as a surfactant in foam concrete. Its ability to stabilize foam structures makes it suitable for lightweight concrete applications, potentially lowering costs and minimizing environmental impact (Momoh, & Osofero, 2019). Surfactants derived from palm kernel oil are biodegradable, non-toxic, and environmentally friendly, which makes them a suitable candidate for sustainable construction materials (Ogunkunle et al., 2022). They also improve the foam stability and density, thus improving the strength-to-weight ratio of foam concrete.

Research on palm kernel oil-based surfactants has focused on optimizing the oil-to-water ratio, pH, and mixing process to produce stable, high-quality oils. Studies suggest that palm kernel oil surfactants can improve the stability of air voids in concrete, leading to enhanced compressive and flexural strengths. However, the performance of this natural surfactant under different curing conditions and at varying densities requires further study.

Several studies have demonstrated that surfactants, especially those from natural oils, improve foam stability and reduce the water-cement ratio, which enhances the compressive strength and overall durability of foam concrete (Meera & Gupta, 2020).

The use of palm kernel oil in concrete production is part of a broader movement toward sustainable construction materials. By replacing synthetic surfactants with renewable, plant-based alternatives, the carbon footprint of foam concrete can be reduced. This aligns with global efforts to make the construction industry more sustainable.

2.3 Lateritic Soil as a Replacement

Laterite soil was first studied by F. Buchanan in 1905. The name was derived from the Latin word 'Later' meaning brick. Laterite is a soil and rock type rich in iron and aluminum and is commonly considered to have formed in hot and wet tropical areas. This soil is rusty red color because of high iron oxide content. These are formed from the weathering of parent rock. The chemical composition of laterite soil/gravel varies widely based on the genesis, climate conditions, and age of laterization. Lateritic soil contains more than 60% Fe203 and little of Al203.

Fig. 2.1: Laterite Soil

Lateritic soil is a type of clayey material that can be used as an alternative to traditional aggregates or even as a partial replacement for cement in concrete. Laterite soil, a tropical soil rich in iron and aluminum oxides, has been widely studied as a partial replacement for cement and fine aggregates in concrete, due to its availability and cost-effectiveness. Laterite enhances the mechanical properties and reduces the environmental impact of concrete, especially in regions where laterite is abundant. In foam concrete, laterite soil can increase density and strength due to its mineral composition, though optimal replacement ratios must be determined to avoid excessive weight and loss of insulation properties (Nambiar & Ramamurthy, 2006).

2.3.1 ***Mechanical properties and durability*****:** Research indicates that lateritic soil can be used to replace cement or fine aggregates to form a more sustainable construction material. When appropriately treated or stabilized, lateritic soil offers comparable strength to conventional concrete, though challenges related to long-term durability and moisture sensitivity exist.

Researchers have used varying stabilizers to improve the mechanical and engineering characteristics of soils. For instance, biomaterials (bacteria and enzymes) are utilized in bio-cementation techniques such as microbial-induced calcium carbonate precipitation (MICP) and enzyme-induced calcium carbonate precipitation (EICP) because of their “environmentally friendly” features. Microbial-induced calcite precipitation (MICP) as a bio mineralization method has been used for soil stabilization in previous studies. A biochemical process occurs in the MICP method to improve soil properties. The process in which microbial-induced biochemical processes fill the gaps between soil grains is called bio-logging. Since emerging in 1995, the MICP method has been compatible with green construction requirements such that it has had minimal impacts on the environment compared with conventional methods. However, considering the granular material, the MICP method does not significantly stabilize fine-grained soil. Nevertheless, some studies have been conducted on the effectiveness of MICP in stabilizing fine-grained soil. (Wahab, N. A. et al., 2021).

2.3.2 Stabilization of lateritic soil: Laterite soil is a type of tropical soil characterized by high iron and aluminum oxide content, low plasticity, and poor engineering properties. Stabilization of laterite soil is essential to improve its strength, durability, and bearing capacity for construction purposes. The physical properties of laterite soils vary considerably depending on the mineral composition and particle size distribution of the soil particles. Particle size may vary from fine to gravel depending on the origin and formation process, which will affect geotechnical properties such as plasticity and compressive strength. One of the benefits of laterite soil is that it is not easy to dilate by water, depending on the mineral content of the clay (Muhiddin & Tangkeallo, 2020).

Chemical Components	**Molecular Formulation**	**%**
Aluminium	Al2O3	17.72
Silicon	SiO2	19.15
Titanium	TiO2	3.00

Iron	FeO	59.96
Potassium	K2O	0.05
Magnesium	MgO	0.12

Table 2.2. Chemical Components of Laterite Soil (Muhiddin, A. B., & Tangkeallo, 2020)

In combination with stabilizers such as lime or cement, lateritic soil can be used to form construction blocks or concrete, improving its mechanical performance (Jose & Kasthurba, 2021). However, the use of surfactants in lateritic soil-based foam concrete is relatively under-researched and presents an opportunity for innovation.

2.4 Foaming Agents In Foam Concrete

One of the most important components of foam concrete is foam, and foaming agents are used to produce the foam (Falliano et al., 2018). Foaming agents affect the density, porosity, stability, and fluidity of foam concrete. Their main task is to introduce air bubbles into foam concrete. Foam can be produced in two different ways: pre-foaming and mixed foaming methods. Foaming agents can be synthetic, glue resins, protein-based, detergents, resin soap, saponin, and hydrolyzed protein. However, the most commonly used foaming agents are synthetic and protein-based ones (Panesar, 2013; Falliano et al., 2018). Protein-based agents allow for a stronger pore structure and a more closed void space network. They create a more stable air-void network. Synthetic agents, on the other hand, allow for more expansion, resulting in lower densities. Synthetic agents are more economical and easier to use than protein agents and also require less energy for storage (Falliano et al., 2018; Bindiganavile & Hoseini, 2019). Falliano et al. (2018) reported that a constant water/cement ratio resulted in more stable foam concrete samples than those obtained from protein-based agents. Ranjani and Ramamurthy (2010) carried out an analysis of the foam produced using sodium lauryl sulfate (SLS) as a surfactant. They found that the foam produced with SLS could not maintain the liquid in the foam, leading to a 40% reduction in density after 0 minutes. They also reported that as the dilution amount of SLS increases, the drainage increases.

Foaming agents, are a critical component in foam concrete. They enable the production of stable, lightweight, and insulating concrete by generating and stabilizing air bubbles within the mix. In traditional foam concrete, synthetic foaming agents, such as protein-based or synthetic surfactants, are commonly used; however, there is growing interest in developing bio-based alternatives like palm kernel oil-based surfactants. This shift toward bio-based foaming agents aims to improve sustainability, reduce environmental impact, and enhance concrete's mechanical and thermal properties.

The selection of an appropriate foaming agent is essential for optimizing the performance of foam concrete. Factors such as foam stability, bubble size distribution, and compatibility with cementitious materials must be carefully considered. Studies suggest that the addition of stabilizers, such as silica fume or fly ash, can enhance foam stability and improve the mechanical properties of foam concrete (Hazlin et al., 2017). Additionally, researchers are exploring eco-friendly foaming agents derived from renewable resources, such as palm kernel oil-based surfactants (PKOS), which offer an environmentally sustainable alternative (Shah et al., 2021).

Palm kernel oil (PKO) contains a variety of fatty acids that facilitate foam formation and stabilization, making it an effective natural surfactant (Li & Wu, 2021). Several studies have explored the use of PKO in foam concrete, demonstrating that it can generate stable foam with comparable properties to synthetic surfactants. PKO's foaming ability comes from the saponification of its fatty acids, which produces soap-like molecules that trap air, forming a stable bubble structure within the cement paste. Researchers have found that PKO-stabilized foam concrete achieves a lighter weight and improved thermal insulation, aligning with the requirements for eco-friendly and energy-efficient building materials (Olusola & Joshua, 2018).

Foaming agents play a pivotal role in the production of foam concrete by generating and stabilizing air bubbles within the concrete mix, thereby reducing density and enhancing thermal insulation. The bubbles act as voids that contribute to the low density and improved insulation properties of foam concrete. The effectiveness of a foaming agent is largely determined by its ability to produce uniform, stable bubbles that remain intact during mixing, pouring, and setting. Studies by Jones and McCarthy (2005) showed that the quality of foaming agents directly affects foam concrete properties such as density, compressive strength, and thermal insulation.

There are different types of foaming agents used in foam concrete production and each type has its unique properties and is selected based on specific project requirements e.g. synthetic agents, and protein-based agents. Each type has its unique properties and is selected based on specific project requirements.

Synthetic foaming agents: often derived from chemicals such as sulfates and alkyl ether, are capable of generating fine, consistent bubbles. These agents are stable and work well across a range of temperatures, making them suitable for both lightweight and structural concrete applications. However, their chemical origin often results in lower biodegradability and potential environmental impact.

Protein-based foaming agents: Derived from natural sources like animal proteins, these agents produce bubbles with high stability and are commonly used in applications where high-strength foam concrete is required. Research by Narayanan and Ramamurthy (2000) has shown that protein-based foaming agents contribute to better mechanical properties in foam concrete compared to synthetic foaming agents.

Foamed concrete performance is significantly impacted by the nature and dosage of the foaming agent. Protein and synthetic foaming agents are widely utilized in the manufacturing of foamed concrete. The protein-based foaming agent is derived from animal blood gum and the synthetic foaming agent contains sodium laureth sulfate. Several researchers carried out preliminary studies on foaming agents and their effect on foamed concrete. Under the helm of these researches, compressive strength is found to have a close relationship with density, capturing adverse effects on compressive strength with reduced density. The effect of water-cement ratio and foam volume size of fine aggregates, curing method, the addition of fiber, pore size, and replacement of cement with fly ash and other supplementary materials on strength parameters have been studied. A study on the mechanical properties of foamed concrete using various kinds of foaming agents has yielded somewhat inconsistent results. The researcher found a better output of protein-based foam concrete, while the researcher detected synthetic foamed concrete on the higher side, thereby reinforcing the need for further study. Drying shrinkage is another important property limiting the use of foam concrete. Lack of coarse and fine aggregates results in 4–10 times greater drying shrinkage in foamed concrete than in standard concrete. Hydration products in foamed concrete predominantly governed its shrinkage. Other factors affecting the drying shrinkage are the cement-filler ratio and filler type, foam volume, and different foaming agents (Hashim & Tantray, 2021).

2.5 Optimization of Mix Design in Hybrid Foam Concrete

The optimization of foam concrete mix design aims to balance factors like strength, workability, and density. Factors such as the type and quantity of surfactant, water-cement ratio, and type of aggregates (including lateritic soil) significantly impact the performance of the final product. Recent advancements in computational tools, like artificial neural networks (ANN) and machine learning, have enabled precise optimization of mix designs based on desired properties (Yang et al., 2023).

Incorporating lateritic soil in hybrid foam concrete mixes offers an opportunity to create sustainable, cost-effective materials, but the mix design must be optimized to maintain both the strength and insulating properties of the concrete. Various experimental studies have demonstrated that the foam concrete mix can be optimized using a combination of different admixtures, including surfactants and stabilizers (Raji et al., 2022).

Another challenge relates to optimizing the mix design to balance the mechanical properties and thermal insulation of hybrid foam concrete. High levels of sawdust may decrease compressive strength, making it less suitable for structural applications. Therefore, further experimentation is required to determine optimal proportions of PKO, sawdust, cement, and water for different construction purposes (Olusola & Joshua, 2018).

The use of Response Surface Methodology (RSM) or other experimental designs can help determine the optimal mix proportions for foam concrete. These techniques allow researchers to assess the impact of different surfactant concentrations and lateritic soil contents on the concrete's compressive strength, workability, density, and thermal insulation. This data-driven approach is crucial for developing hybrid foam concrete mixes that meet both performance and sustainability goals (Nambiar & Ramamurthy, 2006).

Recent research highlights the use of sustainable materials to optimize foam concrete. Palm kernel oil-based surfactants, fly ash, silica fume, and natural soil (e.g., lateritic soil) are increasingly used to enhance the mechanical properties and eco-friendliness of foam concrete. These materials reduce reliance on traditional cement, lowering carbon emissions while improving properties like shrinkage resistance and thermal insulation (Zhang et al., 2015).

Optimizing the compressive and flexural strength of foam concrete is a priority for structural applications. Studies show that adding fibers, such as polypropylene or natural fibers, enhances tensile and flexural strength. For higher compressive strength, densified silica fume or nano-silica is often incorporated (Zahiri & Eskandari-Naddaf, 2019).

Optimization of hybrid foam concrete involves determining the ideal proportions of cement, sand, water, foam, palm kernel oil-based surfactant, and lateritic soil to achieve desired properties. Methods such as response surface methodology (RSM), factorial analysis, and machine learning algorithms have been employed to refine mix proportions efficiently. RSM, for example, has proven effective in evaluating the interactions between multiple variables, such as surfactant concentration, water-cement ratio, and foam content, to identify optimal mix designs. Nambiar and Ramamurthy (2008) applied RSM in foam concrete optimization, resulting in improved strength and density parameters suitable for structural applications. As research advances, foam concrete will continue to evolve as a versatile and eco-friendly material for modern construction.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This research employs an experimental approach to optimize the hybrid foam concrete mix design by incorporating palm kernel oil-based surfactants and lateritic soil. This methodology focuses on designing, testing, and analyzing mixed compositions to achieve an optimal balance between density, strength, and water absorption.

This research was carried out in stages; the first stage involves sourcing for and preparation of Materials, at the second stage, trial mix of foam concrete was conducted to achieve a mix design for the concrete mix while the next stage involves the casting of concrete cubes (150 mm x 150 mm x 150 mm) and the last stage involved the testing of concrete cubes at 1:2 (60% stone dust and 40% laterite soil) nominal mix for foam concrete and a water/cement ratio of 0.8.

3.2. Materials Needed

The materials used for this research work are mainly cement, water, aggregate (stone dust and laterite soil), Palm Kernel Oil and Foaming Agents. These materials were used for casting of 150mm x 150mm x 150mm cubes size. The batching was made for the mix ratio 1:2 and the concrete produced was cast into the cube using mould of 150 mm x 150 mm x 150 mm. After the casting, the mould was removed after 24 hours and the samples were immersed into the curing container. The curing period will be for 7, 14 and 28 days and crushing test, density and water absorption test will be done. The materials are briefly explained below:

3.2.1 Portland limestone cement: Portland Limestone Cement Typically Grade 42.5R, as specified in ASTM C150-20 and BS EN 197-1:2011 was used during this research. The cement serves as the primary binder in foam concrete. The cement is gotten from a cement store around the school area in Ilorin, Kwara State. Each bag of PLC is 50kg in size.

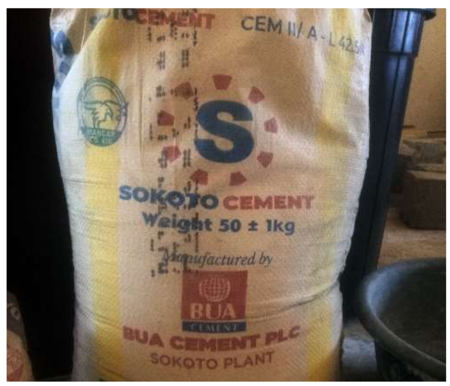

Fig 3.1. Sokoto Cement of 42.5R

3.2.2 Lateritic soil: Laterite soil is used as a partial replacement for fine aggregates in foam concrete and it provides strength and durability for concrete. Lateritic soil samples are been collected from around the school premises. The soil is been sieved through a 1.7 mm sieve as per BS 1377 standards.

Fig 3.2. Laterite Soil in Bag

3.2.3 Stone dust (Hybridized Coarse Aggregate): Stone dust is been introduced as a hybridized coarse aggregate in the mix. Since, there is no need for coarse aggregate

Fig 3.3. Stone Dust from nearby quarry.

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 is verified as per ASTM C33/C33M.

3.2.4 **Palm kernel oil-based surfactants**: Palm kernel oil-based surfactants are derived from the oil extracted from the seeds of the palm kernel through processes such as polyesterification or amidopropylation. PKO-S is been gotten from a nearby market around Ilorin metropolis.

3.2.5 **Water:** Water is essential for hydration and foam generation. Potable water is 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

3.2.6 **Foaming agent:** Sodium Lauryl Sulfate (SLS) is a commonly used foaming agent in foamed concrete. The SLS is sourced for in OJA TUNTUN market, Ilorin.

3.3 Methods

Three different samples of foamed concrete were produced for optimization. Optimization will be between a sample with PKO-S and LS and another without PKO-S. The mix ratio used for both samples is 1:2, where 1 is the ratio for the binder (PLC), 2 is the ratio divided between the aggregates (Laterite soil 40% and Stone dust 60%). The foaming agent varies in response to the water cement ratio.

Mixing procedure:

- Weigh and mix the PLC, Laterite Soil, and Stone dust in a dry mixer until well combined
- In a separate container, mix the SLS in a small amount of water to create a foam solution.
- Add Water to the dry mix and mix until a uniform paste is obtained.
- Mix the generated foam into the wet mix until well combined.
- Add the Palm Kernel Oil into the mix.
- Mix the hybridized foam concrete for an additional 2-3 minutes before pouring and curing for the specified amount of time.

Mix proportioning:

- Mixes is been prepared with lateritic soil content as a partial replacement for fine aggregate.
- PKO-S concentrations varies between 0%, 1.5% and 3.0%.

- The water-to-binder ratio follows the required water-to-cement ratio.
- The Foaming agents also is in concentration with the water – cement ratio.
- Specimens (150 mm x 150 mm x 150 mm cubes) were casted, compacted, and cured in water for 7, 14, and 28 days.

fig 3.4 : Mixing of Specimens

fig 3.5 : Casting of Specimen Cubes

3.4 Tests

Various types of tests were carried out on the sample to check for the compressive strength, water absorption and density of the Foam Concrete, and to know the effect of Palm Kernel Oil Based Surfactant on the sample. The following tests were carried out by following the code of practice:

a. Compressive strength: The compressive strength test is a standard method for determining the strength of concrete. The compressive strength test was conducted using the ASTM C39/C39M standard. During this research, 18 cubes of 150 mm x 150 mm x 150 mm of concrete was been casted and cured for 7, 14 and 28 days (2 cubes for each concentration of PKO) in water of average room temperature after 24 hours of casting. The specimens were tested for compressive strength by applying compressive load to the specimen until it fails. Therefore, the maximum load is recorded which is given by N/mm^2. The compressive strength is then calculated using the formula:

$$\text{Compressive Strength} = \frac{\text{Maximum Load}}{\text{Cross} - \text{sectional Area}}$$

Where:

Maximum load (N) = The maximum load from the machine until failure

Cross – sectional Area (mm^2) = The area of the cube

b. Water absorption: It's determined by submerging the specimens in water for 24 hours and calculating the percentage increase in mass, following (ASTM C642). This test provides the insight into the material's porosity and permeability. The samples were sun-dried, submerged in water for 24 hours, and reweighed to calculate water absorption.

c. **Density**: The specimens after been cured for 7, 14 and 28 days were been weighed to calculate for the density of the specimens following the code of practice standards. The density is been calculated in g/cm^3.

fig 3.6 : Weighed Materials before mixing

fig 3.7 : Sieving of Stone dust

fig 3.8 : Sieving of Laterite Soil.

Fig. 3.9 : Cubes in Curing Buckets

Fig 3.10: Crushing of Concrete Specimen

Fig 3.11: Compressive Test Machine

Fig 3.12: Cubes Samples Before Crushing

Fig 3.13: Removal of Samples After Crushing

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Properties of Materials

The table below shows the properties and number of materials used in this research project.

Table 4.1 Properties and Number of Materials Used

Materials	**Density (Kg/m^3)**
Stone Dust	1800
Laterite Soil	1800
Cement	1440
SLS	
Water/Cement	0.8
PKO	0%, 1.5%, 3.0% of cement

4.2 Density

The tables below show the weight of each specimen cubes in 7, 14 and 28 days

Table 4.2 Weight of specimen cubes in 7 days

Days	**% of PKO**	**Weight (g)**
	0%	6117
	0%	6227
7	1.5%	6664

	1.5%	6852
	3.0%	7134
	3.0%	7183

Table 4.3 Weight of specimen cubes in 14 days

Days	% of PKO	Weight (g)
14	0%	6196
	0%	6247
	1.5%	6704
	1.5%	7003
	3.0%	7212
	3.0%	7214

Table 4.4 Weight of specimen cubes in 28 days

Days	% of PKO	Weight (g)
28	0%	6281
	0%	6413
	1.5%	6794
	1.5%	7042
	3.0%	7662
	3.0%	7580

Table 4.5 Average weight of specimens for 7, 14 and 28 days

Days	% of PKO	Weight (g)
7	0%	6172
	1.5%	6758
	3.0%	7159
14	0%	6222
	1.5%	6854
	3.0%	7213
28	0%	6347
	1.5%	6918
	3.0%	7621

Table 4.6 Density of the specimens

Days	% of PKO	Average weight (g)	Density (Kg/m^3)
7	0%	6172	1830
	1.5%	6758	2000
	3.0%	7159	2120
14	0%	6222	1840
	1.5%	6854	2030
	3.0%	7213	2140
28	0%	6347	1880
	1.5%	6918	2050
	3.0%	7621	2260

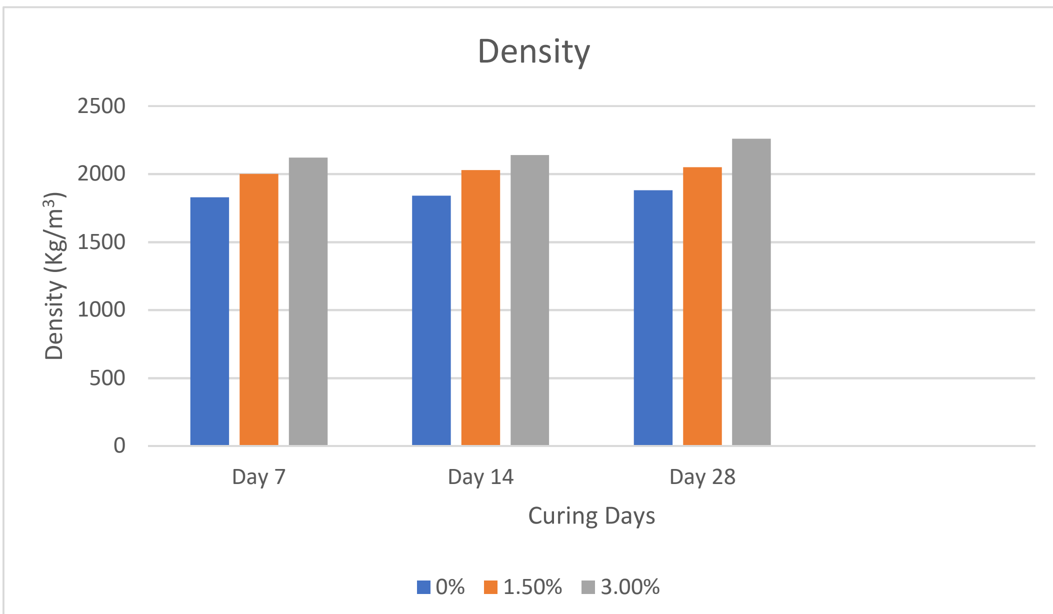

Fig 4.1: Density Chart

According to Table 4.6, the density of the specimens varies according to the curing day, which range between 7, 14 and 28 days. The chart shows the optimal strength between the foam concrete without PKOS and the one with the surfactant. Fig 4.1 show the graphical representation of the optimization of the foam concrete using surfactant and laterite soil in foam concrete.

4.3 Compressive Strength Test

The compressive strength test is the most common test carried out on hardened concrete, because most of the desirable characteristics properties of concrete are qualitatively related to its compressive strength. The result of this test is used as a basis for quality control of concrete proportioning, mixing, placing operations and determination of compliance with specification.

For this project, batching by weight was adopted and the 7th, 14th and 28th day compressive strength of foam concrete using laterite soil and palm kernel oil as surfactant, for a nominal mix ratio of 1:2 (60% Stone Dust and 40% Laterite Soil), at water/cement ratio of 0.8. The results are as shown below

Table 4.7: Compressive strength of sample at 7, 14 and 28 days of curing.

Days	% of PKO	Average weight (g)	Average Failure Load (KN)	Compressive Strength (N/mm^2)
7	0%	6172	70	3.1
	1.5%	6758	35	1.5
	3.0%	7159	40	1.8

14	0%	6222	75	3.3
	1.5%	6854	45	2.0
	3.0%	7213	25	1.1
28	0%	6347	90	4.0
	1.5%	6918	67.5	3.0
	3.0%	7621	75	3.3

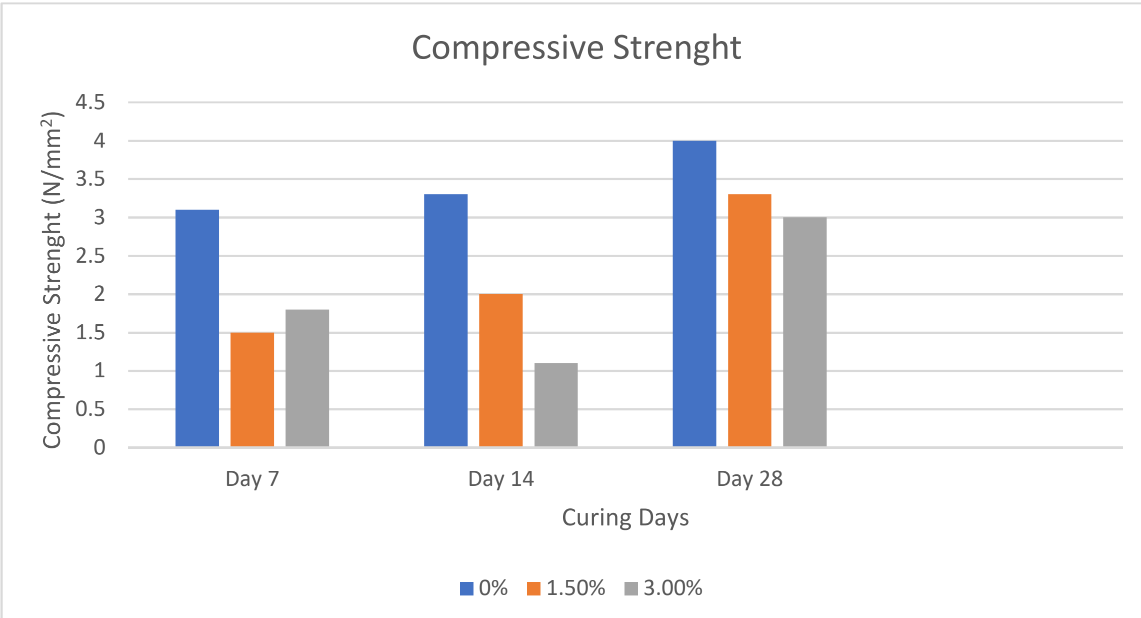

Fig 4.2: Compressive Strength Chart

The table 4.7 shows the compressive strength varies as the PKOS causes reduction in the strength of the foam concrete. According to table 4.7 and fig 4.2, the optimization of foam concrete using surfactant such as PKOS shows a more influence in making the foam concrete to be more lightweight.

4. 4. Water Absorption Test

Table 4.8 Water Absorption test results

Description	Value		
	0%	1.5%	3.0%
Weight of the Sun-dried Sample (g)	6068	6024	5842
Weight of the submerged sample after 24hrs (g)	6182	6106	5920
Water Absorption capacity	1.88%	1.36%	1.34%

Table 4.8 shows the absorption of water in the optimization of foam concrete and the influence of PKOS on foam concrete. It shows a low water absorption rate in foam concrete and it improves the optimal strength of foam concrete.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the results obtained during this study, the following conclusion were made:

1. Specimen density increased with PKOS content, rising from an average of 1 830 kg/m³ at 0% PKOS to 2 120 kg/m³ at 3.0% PKOS after 7 days, with similar trends at 14 and 28 days.
2. The compressive strength of the foam concrete for the different samples after 28 days of curing for samples at 0.8 water/cement ratio varies from 3.3 N/mm2 to 4.0 N/mm2. Which falls within 5-20 N/mm2 specified for light weight concrete.
3. Increasing PKOS reduced water uptake, with absorption falling from 1.88% at 0% to 1.34% at 3.0% PKOS, indicating improved pore structure and durability potential.
4. Adopting a PKOS concentration of 1.5% in hybrid foam concrete for applications requiring moderate structural performance and improved durability, using a 60:40 stone dust: laterite blend improves optimal strength of foam concrete.

5.2 Recommendation

From the result obtained and conclusions made

1. Foam concretes made with PKOS and Laterite Soil at a nominal mix of 1:2 and w/c ratio of 0.8 is suitable for light weight concrete.
2. Investigation into combined effects of nano-additives (e.g., silica fume, nano-silica) and fibers (synthetic or natural) alongside PKOS and LS can be used to further enhance mechanical and durability properties.
3. Since sourcing for PKOS and LS is very affordable, the use of PKOS and LS should be encouraged in the making of foamed concrete.
4. Further studies need to be carried out to improve the compressive strength of Foam concrete either through adding of additives or plasticizers.

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