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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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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, OJO EMMANUEL with matric number, HND/23/CEC/FT/0129 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 **OJO EMMANUEL (HND/23/CEC/FT/0129)** 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.

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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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

The growing demand for sustainable construction materials, coupled with the pressing need to reduce the environmental impact of construction activities, has led to significant interest in the development of alternative concrete materials. Concrete is one of the most widely used building materials, but its production is associated with substantial environmental concerns, including resource depletion, energy consumption, and high carbon emissions. To mitigate these issues, research into alternative concrete formulations has gained traction in recent years. Among the innovations in this field is foam concrete, a lightweight variant of traditional concrete that is gaining attention due to its excellent insulation properties, reduced density, and enhanced workability. Concrete is the most vital building material on the earth. Many civilizations achieved great durability and strength in their concrete production. Environmental issues and need of extensive building material also increased the interest in the research on concrete using waste materials. However, conventionally concrete production emits huge amount of carbon dioxide gases in it. Concrete is an illogical and precious material having about 70% of the total concrete volume (Habibur Rahman Sobuz et al., 2017).

Lightweight foam concrete (LWFC) can be produced from cement, sand, water and foaming agent. It is a lightweight concrete with lower density of concrete (Hazlin et al., 2017). LWFC has density of 400 kg/m3 to 1600 kg/m3 and a minimum of 20% entrapped air in volume. The micro air voids occupied in LWFC has considerably reduced the weight as the air weight is negligible if compared to the concrete. The heavyweight problem of conventional concrete resolved and lead to a fast construction. Hybrid foam concrete has gained significant attention in recent years due to its unique properties, such as lightweight, thermal insulation, and sustainability. Foam concrete is an environmentally friendly, durable and rather cheap artificial stone material received as a result of solidification of the system consisting of cement and sand mix and foam (Sergey et al, 2019).

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 (Shah et al.2021). Foam concrete is an environmentally friendly, durable and rather cheap artificial stone material received as a result of solidification of the system consisting of cement and sand mix and foam (Sergey et al, 2019).

In foam concrete, a highly influential parameter is the percentage of foam content that directly influences the strength, density and stability of the bubble networks of the product. The higher the rate of foam content, the lower the density and compressive strength of the foam concrete (Amran et al, 2015).

According to studies conducted by **Jalal et al. (2017)** foam concrete has sufficient strength to be used as a construction material for the industrialized building system without requiring vibration or compaction to fill cavities and voids over long distances. It enables rapid and settlement-free construction while providing good thermal insulation **E. Ikponmwosa et al. (2017),** excellent freeze/thawing properties, and reliable fire resistance. Foam concrete finds applications in sound and thermal insulation of floors, thermal protection of flat, mono-pitched, and double-pitched roofs, well backfilling, cavity filling, masonry grouting, the production of building blocks and wall panels, thermal insulation, monolithic low-rise and individual house building, road sub-bases, maintenance of bridge abutments, and ground stabilization. Lian et al (2011) found that, similarly to several types of porous media, the strength of porous concrete is significantly affected by the porosity of its internal structure.

The development of LWFC has paved the way for its application in various construction sectors, including residential, commercial, and infrastructure projects (Kearsley & Wainwright, 2001). Its lightweight nature makes it particularly suitable for prefabricated structures, high-rise buildings, and insulation panels (Amran et al., 2015). Additionally, the improved thermal efficiency of LWFC contributes to energy savings in buildings, aligning with global sustainability goals (Hazlin et al., 2017). However, despite its advantages, further research is needed to optimize its mechanical properties and long-term durability to ensure widespread adoption in the construction industry (Jalal et al., 2017).

Palm Kernel Oil based surfactant PKOS, was derived from the widely cultivated oil palm tree, and 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). PKOS is a byproduct of palm oil production, and its use in foam concrete as a natural surfactant could eliminate the need for synthetic foaming agents, offering an eco-friendly solution. Recent studies have shown that incorporating natural surfactants like palm kernel oil into foam concrete could improve workability, reduce segregation, and increase strength over time (Alwi et al., 2020).

Palm kernel oil-based surfactant (PKOS) which is predominantly cultivated in tropical regions is 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).

LWFC is an innovative lightweight variant of traditional concrete that offers numerous benefits, including enhanced insulation properties, reduced density, and improved workability. Its reduced weight makes it a preferable choice in construction where minimizing load is essential, such as in high-rise buildings and prefabricated structures. Furthermore, LWFC exhibits enhanced thermal and acoustic insulation properties, making it highly suitable for energy-efficient buildings. Historically, civilizations have sought to achieve greater durability and strength in concrete production, leading to the continuous evolution of material compositions and construction techniques. However, conventional concrete manufacturing releases substantial amounts of carbon dioxide, contributing significantly to environmental degradation. According to Sobuz et al. (2017), conventional concrete accounts for nearly 70% of the total construction material volume. Additionally, cement production alone is responsible for approximately 8% of global CO2 emissions (Lehne & Preston, 2018). Therefore, exploring sustainable and eco-friendly alternatives, such as LWFC, which utilizes less cement and incorporates industrial by-products or natural stabilizers, is imperative to mitigate the environmental impact of construction activities.

1.2 Problem Statements

Despite its widespread use, traditional concrete presents several drawbacks, including high weight, significant carbon emissions, and resource depletion (Lehne & Preston, 2018). The development of lightweight and environmentally friendly alternatives such as foam concrete is necessary to mitigate these issues (Kearsley & Wainwright, 2001). However, the performance of foam concrete heavily depends on the type and composition of foaming agents, which directly influence its strength, durability, and insulation properties (Amran et al., 2015). The incorporation of natural, biodegradable surfactants such as Palm Kernel Oil-based surfactant (PKOS) and Laterite Soil (LS) has the potential to enhance foam concrete's performance while promoting sustainability (Jones & McCarthy, 2005). However, the effectiveness of these materials in foam concrete applications requires further investigation.

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 Study

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. The following limitations are acknowledged:

Geographical Constraints: The availability of palm kernel oil and lateritic soil varies by region, affecting the generalizability of findings.

Experimental Conditions: Laboratory settings may not fully replicate real-world conditions, potentially influencing the performance of the developed mix.

Economic Analysis: A preliminary economic assessment will be conducted; however, a comprehensive life-cycle cost analysis is beyond the scope of this study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Foam Concrete

Foam concrete is a new-generation material with promising applications in modern construction due to its lightweight properties, insulation benefits, and cost-effectiveness. It is composed of cement, sand, water, and a foaming agent, with a density ranging from 400 kg/m^3 to 1600 kg/m^3. The inclusion of a foaming agent introduces micro air voids, which not only reduce the overall weight of the material but also enhance its thermal and acoustic insulation properties, making it a preferred choice for energy-efficient construction (Hazlin et al., 2017).

The composition of foam concrete significantly affects its physical and mechanical properties. Studies indicate that variations in foam content directly impact the density and compressive strength of the material. A higher foam content results in a lower density and reduced compressive strength, which can influence its load-bearing capacity. However, this reduction in strength is counterbalanced by its superior workability, self-compacting nature, and increased resistance to cracking and shrinkage, making it a viable alternative to traditional concrete in non-structural and semi-structural applications (Amran et al., 2015).

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.

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).

Additionally, foam concrete's adaptability allows for modifications using supplementary cementitious materials such as fly ash, silica fume, or natural fibers. Research suggests that these additives can enhance the durability, strength, and overall performance of foam concrete, offering sustainable solutions in construction (Kearsley & Wainwright, 2001). Furthermore, the reduction in raw material consumption and lower transportation costs associated with its lightweight nature contribute to its growing popularity in eco-friendly building projects (Jones & McCarthy, 2005).

2.1.1 Applications of Foam Concrete

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).

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). Foam concrete is widely utilized in various construction applications, including:

1) Sound and thermal insulation of floors
2) Thermal protection of roofs
3) Well and cavity backfilling
4) Masonry grouting

5) Production of building blocks and wall panels

6) Monolithic low-rise and individual house construction

7) Road sub-bases and bridge abutments

8) Ground stabilization

Research by Jalal et al. (2017) indicates that foam concrete is suitable for industrialized building systems due to its ability to fill voids without requiring vibration or compaction. Additionally, it exhibits excellent fire resistance, freeze/thaw durability, and settlement-free construction properties (Ikponmwosa et al., 2017).

2.1.2 Mechanical and Physical Properties of Foam Concrete

Foam concrete exhibits distinct mechanical and physical properties that vary based on its composition, density, and curing conditions. One of its primary characteristics is compressive strength, which typically ranges from 1 MPa to 25 MPa depending on the density and mix design (Kearsley & Wainwright, 2001). Studies indicate that an increase in foam content reduces compressive strength but improves workability and thermal insulation properties (Jones & McCarthy, 2005).

The flexural strength of foam concrete is generally lower than that of traditional concrete due to its high porosity and lack of coarse aggregates. However, research suggests that the addition of fibers, such as polypropylene or steel fibers, can significantly enhance flexural performance and toughness (Amran et al., 2015). These fibers help improve load distribution and resistance to cracking, making foam concrete more suitable for structural applications.

The density of foam concrete typically ranges from 400 kg/m^3 to 1600 kg/m^3, significantly reducing dead load and making it an attractive option for lightweight construction. Lower densities are ideal for insulation and non-load-bearing applications, while higher densities offer increased compressive strength and structural stability (Jalal et al., 2017). The variation in density also influences other properties such as durability, permeability, and resistance to moisture ingress.

Foam concrete has excellent thermal insulation properties, with thermal conductivity values ranging from 0.1 W/mK to 0.4 W/mK, depending on its density and mix composition (Hazlin et al., 2017). This makes it particularly suitable for energy-efficient buildings, reducing heating and cooling costs. Additionally, its sound insulation capabilities are superior to those of conventional concrete, effectively minimizing noise transmission in residential and commercial spaces (Shah et al., 2021).

Another critical aspect of foam concrete is its durability. Studies indicate that due to its reduced permeability and absence of coarse aggregates, foam concrete exhibits good resistance to sulfate attack, freeze-thaw cycles, and fire exposure (Lehne & Preston, 2018). Proper curing and mix design optimization further enhance its longevity, making it a viable option for sustainable construction projects.

Another crucial mechanical property of foam concrete is its flexural strength, which is generally lower than that of conventional concrete due to its porous structure. However, additives such as fibers and pozzolanic materials can enhance flexural performance and ductility (Amran et al., 2015).

The dry density of foam concrete typically ranges from 400 kg/m^3 to 1600 kg/m^3, making it significantly lighter than conventional concrete. Lower-density foam concrete is commonly used for insulation and non-structural applications, whereas higher-density mixes are used in load-bearing construction (Jalal et al., 2017).

Foam concrete's thermal insulation properties are superior to those of traditional concrete due to its entrapped air voids. Its thermal conductivity varies from 0.1 W/mK to 0.4 W/mK, making it an effective material for energy-efficient buildings (Hazlin et al., 2017). Additionally, foam concrete offers excellent sound insulation, reducing airborne noise transmission in buildings (Shah et al., 2021).

In terms of durability, foam concrete demonstrates excellent resistance to fire, freeze-thaw cycles, and sulfate attack due to its lower permeability and absence of coarse aggregates. Studies have shown that properly cured foam concrete can maintain its strength and performance over extended periods without significant degradation (Lehne & Preston, 2018).

2.2. Role of Surfactants in Foam Concrete

Surfactants play a crucial role in stabilizing foam within the concrete matrix. They reduce surface tension, enabling the formation of a stable network of air bubbles, which contributes to the lightweight and insulating properties of foam concrete. Conventional foaming agents are often derived from alcohol-based, animal fat-based, or vegetable oil-based sources (Shah et al., 2021). However, with the increasing focus on sustainability, there has been a growing interest in biodegradable and eco-friendly alternatives.

One such sustainable surfactant is Palm Kernel Oil-based surfactant (PKOS), which has demonstrated excellent foaming stability and uniform air void distribution in foam concrete (Jones & McCarthy, 2005). Studies suggest that PKOS improves mechanical properties such as compressive strength and workability, making it a viable alternative to synthetic foaming agents. Furthermore, PKOS is a byproduct of palm oil production, which contributes to waste reduction and aligns with sustainable construction practices (Alwi et al., 2020).

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).

Laterite Soil (LS) has also been investigated as a potential natural stabilizer in foam concrete. LS, known for its high iron and aluminum oxide content, enhances the stability of the foam structure and improves the overall durability of foam concrete (Kearsley & Wainwright, 2001). Research has shown that incorporating LS in foam concrete enhances its cohesiveness, reducing the risk of segregation and increasing long-term structural integrity (Amran et al., 2015).

Additionally, the concentration of surfactants significantly influences the performance of foam concrete. A higher surfactant content leads to an increased volume of air voids, resulting in lower density and reduced compressive strength. However, optimized surfactant proportions can enhance foam stability while maintaining sufficient mechanical strength (Jalal et al., 2017). The selection of surfactants must therefore be carefully balanced to achieve the desired properties for specific applications in construction.

Recent advancements in surfactant technology have also explored the use of protein-based and bio-surfactants, which offer superior foam stability and environmentally friendly attributes. These bio-surfactants have demonstrated potential in enhancing foam concrete’s fire resistance and thermal insulation properties (Hazlin et al., 2017). Further research is necessary to optimize these natural surfactants and integrate them into commercial foam concrete applications.

Overall, surfactants play a fundamental role in defining the properties of foam concrete, affecting its density, stability, and mechanical strength. The transition towards eco-friendly surfactants such as PKOS and LS not only enhances sustainability but also provides a cost-effective and efficient alternative for the construction industry (Lehne & Preston, 2018).

2.3 Influence of Laterite Soil (LS) in Foam Concrete

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.

Laterite Soil (LS) is a natural material found predominantly in tropical and subtropical regions. It is rich in iron and aluminum oxides, which contribute to its stabilizing properties when used in construction materials (Kearsley & Wainwright, 2001). LS has gained attention in recent years due to its availability, cost-effectiveness, and potential to improve the mechanical and durability properties of foam concrete (Jones & McCarthy, 2005).

One of the main benefits of incorporating LS in foam concrete is its ability to enhance foam stability, reducing segregation and increasing cohesion within the concrete matrix (Amran et al., 2015). The fine particles in LS interact with the cementitious components, leading to better bonding and improved microstructural integrity (Jalal et al., 2017). This results in increased compressive strength and improved resistance to environmental degradation.

Additionally, LS contributes to the sustainability of foam concrete by utilizing locally sourced materials and reducing the need for artificial stabilizers (Lehne & Preston, 2018). This makes foam concrete with LS an eco-friendly alternative, especially in regions where laterite is abundantly available. Studies indicate that foam concrete incorporating LS can achieve satisfactory mechanical performance, making it suitable for non-structural and semi-structural applications, such as insulation panels and lightweight blocks (Hazlin et al., 2017).

Furthermore, LS enhances the thermal insulation properties of foam concrete by optimizing the pore structure and reducing thermal conductivity (Shah et al., 2021). This makes it particularly useful for energy-efficient buildings and infrastructure projects where thermal performance is a key consideration. The combination of LS with other sustainable additives, such as Palm Kernel Oil-based surfactant (PKOS), further improves foam concrete’s workability and durability (Alwi et al., 2020).

Although LS offers several benefits, challenges such as increased water demand and variability in composition must be carefully managed through proper mix design and quality control (Kearsley & Wainwright, 2001). Future research should focus on optimizing LS-based foam concrete formulations to maximize its mechanical and environmental performance while maintaining cost-effectiveness in large-scale applications.

2.3.1 Mechanical and Physical Properties of Laterite Soil

Laterite soil exhibits unique mechanical and physical properties that make it a valuable material for construction applications. It is known for its high iron and aluminum oxide content, which provides excellent binding properties when mixed with cementitious materials (Kearsley & Wainwright, 2001). These oxides enhance pozzolanic reactions, leading to improved strength development over time (Amu et al., 2011). Additionally, laterite soil has good cohesion and compaction characteristics, which contribute to its structural stability in various construction applications (Olugbenga et al., 2013).

The compressive strength of laterite soil varies depending on its composition and moisture content, but stabilized lateritic soil can achieve compressive strengths ranging from 2 MPa to 8 MPa, making it suitable for non-structural and semi-structural applications (Jones & McCarthy, 2005). Studies have shown that the use of cement, lime, or other stabilizing agents can significantly enhance the compressive strength, with lateritic concrete reaching strengths comparable to conventional cement-based materials (Osinubi et al., 2009). Furthermore, the particle size distribution and mineralogical composition of laterite soil influence its mechanical performance, affecting its suitability for different construction needs.

Laterite soil has a density typically ranging from 1400 kg/m^3 to 1800 kg/m^3, making it denser than foam concrete but lighter than conventional aggregates. This intermediate density makes it an effective stabilizing agent when incorporated into lightweight concrete formulations (Amran et al., 2015). Moreover, laterite soil demonstrates relatively high water absorption due to its porous nature, which can influence the overall workability and curing requirements of concrete mixtures (Jalal et al., 2017).

Thermal insulation is another key property of laterite soil, contributing to energy-efficient construction practices. Studies indicate that lateritic materials exhibit lower thermal conductivity compared to conventional aggregates, making them suitable for climate-responsive building designs (Hazlin et al., 2017). Additionally, laterite soil has demonstrated good resistance to sulfate attack and moderate durability under varying environmental conditions, making it a viable alternative to traditional aggregates in sustainable construction (Shah et al., 2021).

The density of laterite soil typically falls within the range of 1400 kg/m³ to 1800 kg/m³, which is relatively lower than traditional aggregates but higher than foam concrete. This makes it an effective stabilizing agent when incorporated into lightweight concrete formulations (Amran et al., 2015). The soil's porous nature enhances water retention and workability, although proper curing is required to prevent excessive shrinkage and cracking (Jalal et al., 2017).

Thermal insulation is another key property of laterite soil, contributing to energy-efficient construction practices. Studies have indicated that lateritic materials exhibit lower thermal conductivity compared to conventional aggregates, making them suitable for climate-responsive building designs (Hazlin et al., 2017). Additionally, laterite soil has demonstrated good resistance to sulfate attack and moderate durability under varying environmental conditions (Shah et al., 2021).

2.4 Foaming Agents in Foam Concrete

Foaming agents play a crucial role in the production of foam concrete, as they facilitate the formation of air voids within the concrete matrix. These agents reduce surface tension, allowing for the creation of a stable foam structure that influences the density, thermal insulation, and mechanical properties of foam concrete (Kearsley & Wainwright, 2001). The effectiveness of a foaming agent is determined by its ability to produce stable bubbles that do not collapse during the mixing and curing process (Jones & McCarthy, 2005).

Foaming agents can be classified into two main categories: protein-based and synthetic-based agents. Protein-based foaming agents are derived from natural sources such as animal proteins or plant extracts and are known for producing stronger, more stable foams. These agents improve the durability and mechanical strength of foam concrete, making them suitable for structural applications (Amran et al., 2015). On the other hand, synthetic foaming agents are chemical surfactants that generate foam more efficiently and are easier to handle. However, they may result in lower compressive strength compared to protein-based agents (Jalal et al., 2017).

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).

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 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.

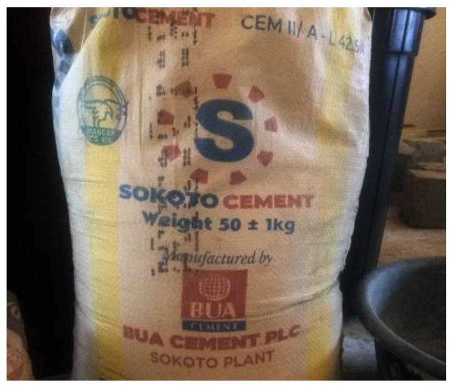

Fig 3.1. Sokoto Cement of 42.5R

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 in foam concrete to reduce its weight and density. Stone dust is collected from

Fig 3.3. Stone Dust from nearby quarry.

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)
7	0%	6117
	0%	6227
	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

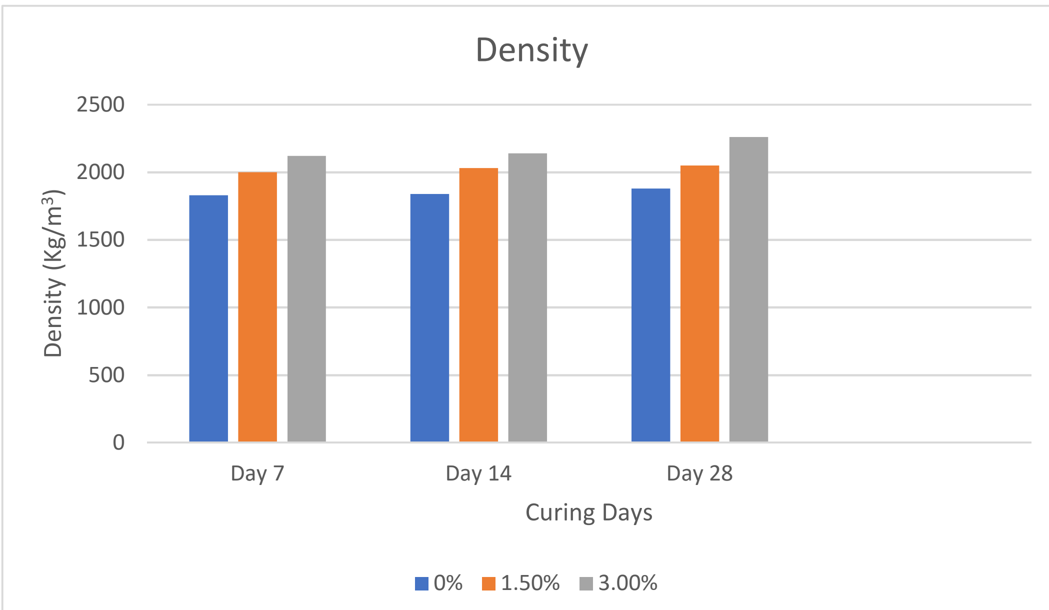

Fig 4.1: Density Chart

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

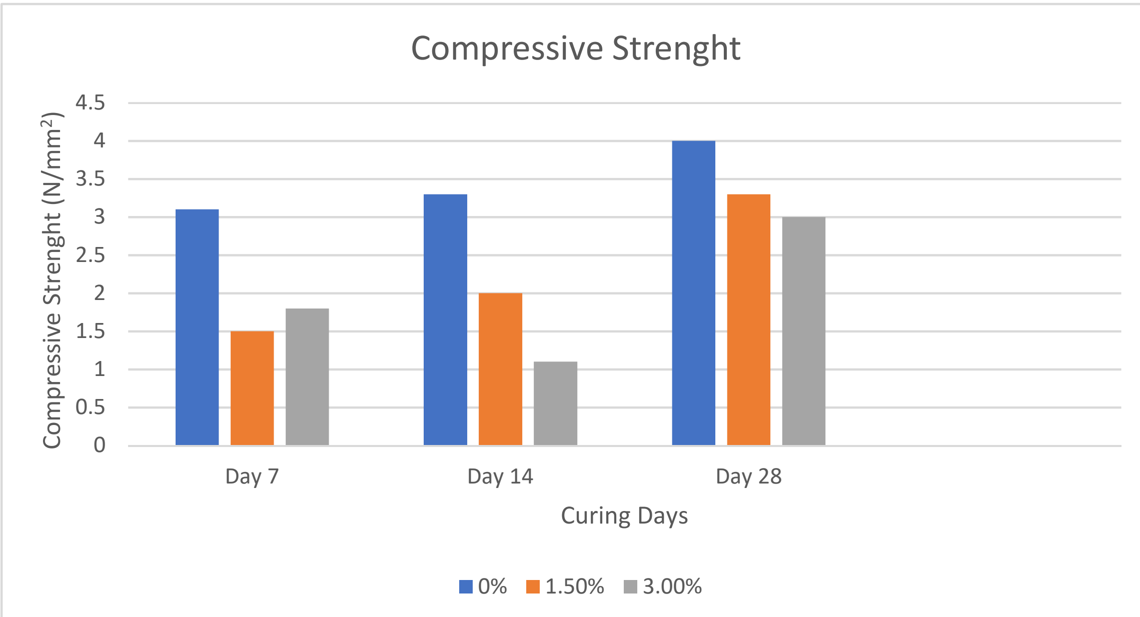

Fig 4.2: Compressive Strength Chart

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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