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

BY

ABDULGANIYU RIDWANULLAHI AYINLA

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CHAPTER ONE
INTRODUCTION

1.1 Background of Study

The rapid development of sustainable construction materials has led researchers to explore innovative alternatives to conventional concrete. One such alternative is foam concrete—a lightweight, cellular material known for its thermal insulation and acoustic properties. In recent years, the development of hybrid foam concrete, which combines conventional cementitious materials with additional components to improve its performance, has gained significant attention. This study focuses on the evaluation of water absorption and density of hybrid foam concrete when modified with palm kernel oil solvent (PKOS). The integration of PKOS is a novel approach aimed at altering the microstructure of the concrete matrix, potentially reducing water ingress and optimizing density for specialized applications.

Foam concrete is traditionally produced by incorporating a stable, pre-formed foam into a cement slurry, thereby introducing a large number of closed air voids into the hardened matrix (Smith & Jones, 2014). This process not only reduces the density but also improves the material's insulating properties. However, one of the main drawbacks of foam concrete is its susceptibility to water absorption due to the interconnected pore network, which can affect durability and long-term performance (Banthia & Gupta, 2006). Previous studies have explored various additives and modifications—ranging from polymers to inorganic fillers—to mitigate these issues. For instance, research by Hassan et al. (2015) demonstrated that the incorporation of certain organic additives could reduce water permeability while maintaining the lightweight characteristics of foam concrete.

Palm kernel oil solvent has recently emerged as a potential additive in concrete technology. Derived from the by-products of palm oil processing, PKOS is rich in fatty acids that can modify the surface tension properties of the concrete matrix. Studies such as those by Adeyemi and Olubambi (2018) have indicated that oil-based solvents can alter the hydration kinetics and pore structure of cementitious materials, leading to improvements in density and reduced water absorption. Given the abundance and relatively low cost of palm kernel oil, its application in hybrid foam concrete represents a sustainable option that could also contribute to waste valorization in palm oil producing regions.

The rationale behind using PKOS in hybrid foam concrete is rooted in its dual ability to act as a modifying agent and a densifier. The fatty acid components in PKOS may interact with the hydration products of cement, leading to the formation of a more refined microstructure with fewer capillary pores. A reduction in pore connectivity is expected to lower the rate of water absorption, which is a critical parameter in assessing the durability of concrete. Furthermore, the use of PKOS may improve the overall density of the material, thereby enhancing its load-bearing capacity and resistance to environmental degradation (Chin & Ng, 2010). Such improvements are essential, especially in applications where both weight reduction and structural integrity are paramount.

The body of literature addressing foam concrete has largely focused on its thermal and acoustic insulation properties, as well as its mechanical performance. However, there is a noticeable gap when it comes to comprehensive studies that evaluate the synergistic effects of combining foam concrete with oil-based additives like PKOS. For example, while studies by Kumar et al. (2017) have delved into the influence of various chemical admixtures on the mechanical properties of lightweight concretes, few have specifically addressed how these additives interact with the foam structure at a micro-level. This study seeks to bridge that gap by systematically investigating how PKOS influences both water absorption and density in hybrid foam concrete.

Water absorption in concrete is a critical factor that influences durability, especially in environments subjected to frequent wetting and drying cycles. High water absorption can lead to the deterioration of the cement paste and subsequent loss of mechanical properties. Therefore, understanding the relationship between the modified microstructure of hybrid foam concrete and its water absorption behavior is crucial. In parallel, density is a key performance metric that directly affects the thermal insulation and structural applications of the material. The dual investigation of these parameters under varying levels of PKOS addition will provide comprehensive insights into optimizing the formulation of hybrid foam concrete for enhanced performance (Ahmed et al., 2020).

In developing this study, previous research has provided a strong foundation. Banthia and Gupta (2006) demonstrated the importance of controlling pore structure in foam concrete to achieve desirable mechanical properties. Their work laid the groundwork for subsequent studies, such as those by Hassan et al. (2015), who focused on the durability aspects of modified foam concrete formulations. Furthermore, research by Adeyemi and Olubambi (2018) on oil-based additives highlights the transformative potential of integrating such solvents into cementitious systems, suggesting that the microstructure and durability of the composite material can be significantly improved.

This study is particularly timely given the global emphasis on sustainability in construction. By utilizing an agricultural by-product such as palm kernel oil solvent, the research not only seeks to improve material performance but also contributes to the sustainable use of local resources. The environmental benefits of using PKOS, coupled with the potential cost savings, make it a promising candidate for large-scale applications in regions where palm oil production is prevalent.

The primary objectives of this study are twofold: firstly, to evaluate how the incorporation of PKOS affects the water absorption characteristics of hybrid foam concrete; and secondly, to assess its impact on the density of the material. Through rigorous laboratory testing, including standardized water absorption tests and density measurements, this research will elucidate the mechanisms by which PKOS modifies the internal structure of foam concrete. The outcomes of this study are expected to provide valuable guidelines for the formulation of advanced, sustainable building materials that meet the dual demands of performance and environmental responsibility.

1.2 Statement of the Problem

Despite the growing popularity of foam concrete in lightweight construction, one of the persistent challenges is its inherent susceptibility to water absorption due to its porous nature. High water absorption rates can compromise the durability and mechanical strength of the material, leading to premature degradation when exposed to aggressive environments. Moreover, while various modifications and additives have been explored to mitigate this issue, there remains a significant gap in research concerning the use of oil-based additives—specifically, palm kernel oil solvent (PKOS)—in hybrid foam concrete formulations. The potential of PKOS to refine the pore structure and enhance density has not been comprehensively investigated, leaving uncertainty about its effectiveness and optimal application in reducing water ingress while maintaining or improving the material's structural integrity.

In addition, while conventional studies have focused on the general properties of foam concrete, the interplay between water absorption and density in hybrid formulations modified with PKOS remains largely unexplored. This lack of data poses a challenge for engineers and material scientists who seek to develop sustainable and durable concrete materials, particularly in regions where palm oil by-products are abundant. Consequently, there is a need to systematically evaluate how varying concentrations of PKOS affect the water absorption behavior and density of hybrid foam concrete, thereby addressing both the durability concerns and the need for environmentally sustainable construction practices. This study aims to bridge that knowledge gap by providing empirical evidence and detailed analysis to guide future applications of PKOS in foam concrete technology.

1.3 Aim and Objectives of the Study

The aim of this research study is to evaluate the water absorption and density of hybrid foam concrete using palm kernel oil solvent

The objectives of this study are to;

i. Determine the effect of incorporating palm kernel oil solvent (PKOS) on the water absorption properties of hybrid foam concrete.
ii. Investigate how different concentrations of PKOS influence the density of hybrid foam concrete.
iii. Identify the optimal PKOS dosage that minimizes water absorption while maintaining or enhancing the desired density and overall mechanical properties of the concrete.

1.4. Justification of Study

The study is justified by the need to enhance the durability and performance of foam concrete, which is often limited by its high water absorption due to a porous structure. Incorporating palm kernel oil solvent (PKOS) could refine the microstructure, reduce porosity, and thereby improve the long-term resilience of hybrid foam concrete. This potential improvement is crucial for developing construction materials that can better withstand environmental stressors while maintaining lightweight and thermal insulation properties.

Additionally, using PKOS—a by-product of palm oil production—addresses economic and sustainability concerns by valorizing waste materials and reducing production costs. This research bridges a notable gap in the literature regarding oil-based additives in concrete, contributing valuable insights into optimizing mix designs for enhanced mechanical properties and environmental performance.

1.5 Scope of Study

The scope of this study is confined to the evaluation of water absorption and density in hybrid foam concrete modified with palm kernel oil solvent (PKOS). The research will involve the preparation of various concrete mixes with differing concentrations of PKOS, followed by laboratory tests to measure water uptake over time and determine the corresponding density of the hardened material. The study will also include a basic microstructural analysis to understand the modifications induced by PKOS in the foam concrete matrix.

This investigation will be conducted under controlled laboratory conditions and is limited to analyzing the effects of PKOS on water absorption and density. Other potential properties such as compressive strength, thermal conductivity, long-term durability, and resistance to chemical attacks are beyond the scope of this study. The findings are intended to provide preliminary insights into the viability of using PKOS as an additive for improving foam concrete properties, laying the groundwork for future, more comprehensive studies.

CHAPTER TWO
LITERATURE REVIEW

2.0 Preamble

This chapter of the research work explain the various literature and concept related to the topic of research which is evaluation of water absorption and density in hybrid foam concrete modified with palm kernel oil solvent (PKOS).

2.1 LITERATURE REVIEW

The advent of foam concrete as a lightweight and sustainable construction material has spurred extensive research into its properties and performance enhancements. Traditionally, foam concrete is produced by entraining a stable foam into a cementitious matrix, thereby creating a material with a high volume of air voids that significantly reduces its density and improves thermal insulation properties (Smith & Jones, 2014). However, the high porosity that contributes to its lightweight nature also poses significant challenges in terms of durability, particularly due to elevated water absorption rates. Banthia and Gupta (2006) emphasized that the interconnected pore network in foam concrete can lead to rapid water ingress, which compromises both the structural integrity and longevity of the material. This early body of work laid the foundation for subsequent studies aimed at mitigating these durability issues by refining the pore structure through various chemical and physical modifications.

Building on this foundation, Hassan et al. (2015) investigated the effect of organic additives on reducing water permeability in foam concrete. Their research demonstrated that certain organic compounds, when introduced into the mix, could effectively reduce the connectivity of the pores, thereby lowering water absorption without significantly affecting the inherent lightweight properties of the material. In a similar vein, Chin and Ng (2010) explored the influence of fatty acid-based additives on the microstructure of concrete. They found that such additives not only contributed to a denser matrix but also improved the overall durability of the concrete by mitigating capillary suction. These studies collectively suggest that modifying the pore structure via chemical additives is a promising pathway to enhance the performance of foam concrete in moisture-prone environments.

Recent investigations have turned attention to more sustainable and cost-effective additives derived from agricultural by-products. Adeyemi and Olubambi (2018) were among the first to examine the application of palm kernel oil solvent (PKOS) in cementitious materials. Their study revealed that the fatty acids present in PKOS interact with the hydration products of cement, leading to a refined pore structure and, consequently, a reduction in water absorption. This finding is particularly significant in regions with abundant palm oil production, where PKOS can serve as an eco-friendly and economical additive. Kumar et al. (2017) further advanced this line of inquiry by evaluating the role of various chemical admixtures in enhancing the performance of lightweight concrete. Although their research primarily focused on the compressive strength and workability of the mixtures, the implications for density and durability were clear: optimal admixture proportions could significantly enhance the material's performance while maintaining its lightweight benefits.

In addition to these studies, Ahmed et al. (2020) highlighted the importance of sustainable modifications in concrete technology. Their work demonstrated that incorporating by-products such as PKOS not only improves the microstructural characteristics of concrete but also contributes to environmental sustainability by valorizing waste materials. This dual benefit of enhanced performance and environmental impact has galvanized further research into hybrid foam concretes, where the integration of organic additives aims to balance mechanical strength with durability. Moreover, emerging studies have begun to explore the synergistic effects of combining multiple additives. For instance, some researchers have experimented with nano-silica and fly ash in conjunction with organic solvents, reporting improvements in both density and water resistance. However, these investigations remain limited in scope, and the specific interaction between PKOS and the foam concrete matrix in hybrid systems is not yet fully understood.

A critical gap in the current literature is the lack of comprehensive studies that address both water absorption and density simultaneously in hybrid foam concretes modified with PKOS. While individual studies have focused on either enhancing durability or optimizing density, the interplay between these two critical properties has not been extensively explored. The hybrid nature of the foam concrete under investigation—in which traditional cementitious materials are combined with a foaming agent and modified by PKOS—introduces complex interactions that affect the overall performance of the material. Understanding these interactions is crucial, as improvements in density must not come at the expense of increased water permeability. Therefore, systematic laboratory investigations are needed to quantify the effects of varying concentrations of PKOS on both water absorption and density, providing a more holistic view of the material's behavior.

In summary, the literature reveals a clear trajectory from initial studies on foam concrete's lightweight and insulating properties toward a more nuanced understanding of its durability challenges. While early research by Banthia and Gupta (2006) and Hassan et al. (2015) established the detrimental effects of high porosity, subsequent work by Chin and Ng (2010) and Adeyemi and Olubambi (2018) has begun to address these challenges through chemical modifications. The current study aims to bridge the gap by investigating the dual effects of PKOS on water absorption and density in hybrid foam concrete. This research not only contributes to the ongoing dialogue on sustainable construction materials but also offers practical insights for optimizing concrete formulations in moisture-sensitive applications.

2.2 Concrete

The development of concrete as a construction material dates back several thousand years to the days of ancient Egyptians, the Greeks and the Romans. These early concrete compositions were based on lime, although the Romans are known for their development of pozzolanic cement and lightweight concrete (Olaoye, 2013). Apart from brief revivals over the years, there was little further development until the eighteen century when the industrial revolution evolved. Later in the nineteen century, the technique of reinforced concrete was introduced. The credit for introduction of steel as a requirement is variously attributed to Joseph Aspdin 1824, William Wilkinson 1854, Lambot in 1855 for Ferro cement boats, to Monier in 1867 and to Hennebique in 1897 who built the first reinforced concrete frame building in Britain at Weaver’s Mill, Swansea. Notable steps forward in this century have been introduction of pre-stressed concrete by Freyssinet in the 1940s, the extensive use of reinforced concrete during World War II, the rapid post-war concrete building expansion prompted by shortages of steel, the motorway building boom of the 1960s involving concrete pavements and bridges, and most recently, the contribution of structural concrete to modern offshore structures (Elena, 2006).

Concrete is mixture of cement, sand, gravel, and water. Concrete is the most important material in construction industry other than timber and steel. It is estimated that current consumption of concrete in the world is of the order of 10 billion tones once a year. People consume no material except water in such tremendous quantities (Talha and Chaid, 2015). Aggregates occupy 60%to 80% total volume of concrete. Mineral admixtures are often used in concrete in combination with Portland cement for development of mechanical properties, economy, and improved durability under the anticipated environment. Mineral admixtures include rice husk ash, marble powder, fly ash, brick powder, ground granulated blast furnace slag, metakaolin, silica fume and extra. Mineral admixtures are also referred as the performance improvers (Gulden and Recep, 2015). The word concrete is originating from the Latin verb “concretus” that means to grow together. The characteristics of concrete depends upon the properties of constituent of material and their combined action. Within the production of cement CO_2 gas emission is additional, so these leads to injury of natural environmental conditions. To cut back the consumption of cement partial replacement of cement with some supplementary building materials (Ali, 2011). Cement is a binding material that has adhesive and cohesive properties within the presence of water. Such type of cements is called hydraulic cement the hydraulic cement is usually known as Portland cement because of its resemblance upon hardening to the Portland rock found near Dorset, England (Oguzhan and Erdinc, 2014).

2.2.1 Properties of Concrete

The properties of fresh concretes are:

2.2.1.1 Workability

Workable concrete is the one which exhibits very little internal friction between particles and which overcomes the frictional resistance offered by the formwork surface or reinforcement contained in the concrete with just the amount of compacting efforts forthcoming. The factors helping concrete to have more lubricating effect to reduce internal friction for helping easy compaction are water content, mix proportions, aggregate size, grading, surface texture, and shape (Olaoye, 2013).

2.2.1.2 Segregation

Segregation can be defined as the separation of the constituent materials of concrete. A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture. If a sample of concrete exhibit a tendency for separation (coarse aggregate) from the rest of the ingredients, then that sample is said to be showing the tendency for segregation. Such concrete is not only going to be weak, lack of homogeneity is also going to induce all undesirable properties in the hardened concrete (Olaoye, 2013).

2.2.1.3 Bleeding

Bleeding is sometimes referred to water gain. Bleeding is predominantly observed in a highly wet mix, badly proportioned and insufficiently mixed concrete. It is particular form of segregation in which some of the water from the concrete comes out to the surface of the concrete (Olaoye, 2013).

2.2.1.4 Setting Time of Concrete

Setting time of concrete differs from setting time of cement. This depends on the water cement ratio, temperature conditions, type of cement, mineral admixture and use of retarding plasticizer (Olaoye, 2013).

2.3 Constituent Materials of Hybrid Foam Concrete Using Palm Kernel Oil Solvent

2.3.1 Cement

Cement could be a binder, a substance utilized in construction that sets and hardens and can bind other materials together. The most vital types of cements are used as a component within the production of mortar in masonry, and of a concrete, that could be a combination of cement and aggregate to make a strong building material (Ali, 2011). Cements utilized in construction will be characterized as being either hydraulic or non-hydraulic, depending upon the ability of the cement to set within the presence of water. Non-hydraulic cement will not set in wet conditions or under water, rather, it sets because it dries and reacts with CO_2 within the air. It will be attacked by some aggressive chemicals after setting. Hydraulic cement or ordinary Portland cement set in wet conditions and become adhesive due to chemical reaction process between the dry ingredients and water (Gulden & Recep, 2015). The chemical process results in mineral hydrates that are not very water-soluble and so are quite sturdy in water as well as safe from chemical attack. This permit setting in wet condition or under water and further protects the hardened material from chemical attack. The chemical change for cement found by ancient romans used volcanic ash (Ali, 2011).

Cement is a binder. It is a substance that sets and hardens independently and can bind other materials. The most important use of cement is as an ingredient in the production of mortar in masonry and concrete. Cement is made by heating limestone (calcium carbonate) with small quantities of other materials (such as clay) to 1450°C in a kiln, in a process known as calcination, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix. The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make 'Ordinary Portland Cement', the most commonly used type of cement. Portland cement is a basic ingredient of concrete and mortar. The most common use for Portland cement is in the production of concrete (Akhubi, 2014).

Cement is binder that is widely used in construction because of its adhesive and cohesive properties. It provides a binding medium for the ingredients of brick. Cement is functioned to bind the fine aggregates and coarse aggregates together and fill the voids in between both aggregates particles to form a compact mass. Portland cement is a type of cement that is commonly used in construction. It is made from a combination of argillaceous and calcareous materials to a partial fusion at about 1450 °C (Gambhir, 2004).

The argillaceous materials are clay, slate, shale and selected blast-furnace slag. The calcareous materials are usually chalk and limestone. There are two types of method to manufacture cement, dry and wet process. Normally dry process is used to produce cement. The materials are first crushed, ground and mixed before fed into a cement kiln and heated at a high temperature of 1450°C. The product after heating is known as clinker is then cooled and ground into fine powder form and cement is formed. On the other hand, the materials needed to grind with water before entering the kiln for wet process. Wet process requires more energy to evaporate the water inside the kiln. However, both processes emit large amount of CO_2 to the atmosphere (Gambhir, 2004).

Cement is generally referred to as Portland limestone cements (CEM II) because in its hardened state it resembles the Portland limestone in colour and texture. Cement is a binder, a substance which sets and hardens independently, and can bind other materials together. Cement according to Allen (2008), can be manufactured from any number of raw materials, providing they are combined to yield the necessary amounts of lime, iron, silica and alumina. Lime comes from limestone, marble and marl or seashells while iron, silica and alumina can come from either clay or shale. Allen (2008) further stated that a variety of Portland limestone cement (CEM II) is produced, each with characteristics suited for a particular use or purpose. (Allen, 2008).

Cement was discovered in 1824 and this discovery brought a new revolution in the building industry. There are different types of Portland cements, including ordinary fast curing, extra fast curing, low heat, sulphate resistant blast furnace, white and pozzolan (Emitt & Gorse, 2005). Among these types of cement, ordinary Portland cement is the cheapest and most commonly used cement and is more readily available. On average, the cost of building materials for a housing structure represents about 50 percent of the total cost of the building (Jones & Dhir, 2000). Olutoge (2010) stated that due to environmental pollution and the high consumption of natural resources such as limestone, clay and the high cost of Portland cement, etc., cement cannot be frequently produced. It is therefore necessary to reduce the use of cement. One of the practical solutions to minimized the use of cement is to replace the cement with additional cementitious materials such as hulled ashes of cassava, ashes of corncob, fly ash of coal, granulated blast furnace slag (GBS), silica fumes, metakaolin (calcined clay), rice husk ash, palm kernel ash**.** (Olutoge, 2010)

Emitt & Gorse (2005) asserts that cement was discovered in 1824, and that this discovery brought a new revolution into the building industry. Emitt and Gorse (2005) further states that different types of Portland cements exist which include ordinary, rapid hardening, extra rapid hardening, low heat, sulphate resisting blast furnace, white and pozzolana. Out of these types of cement however, ordinary Portland limestone cement (CEM II) is the cheapest and the most commonly used cement and it is more readily available. (Emitt and Gorse, 2005)

2.3.2 Hybrid Foam Concrete

Hybrid foam concrete is an advanced composite material that marries the traditional cementitious matrix with a polymeric component, typically incorporating a foamed phase. Unlike conventional foam concrete, which relies solely on entrained air voids produced by foaming agents., the hybrid formulation introduces polymers (for example, polyurethane) into the mix. This approach offers a two-fold benefit: it takes advantage of the well-known hydration process of cement while simultaneously leveraging polymerization reactions to fine-tune mechanical, thermal, and durability characteristics. In applications such as wall panels and insulating elements, these distinct reactions can be independently manipulated to achieve a balance between weight reduction, structural integrity, and thermal performance (Zhou, *et al*., 2018).

2.3.2.1 Composition of Hybrid Foam Concrete

1. **Cementitious Binder:** Ordinary Portland Cement (OPC) is commonly used; however, alternatives like magnesium phosphate cement (MPC) and sulfoaluminate cement (SAC) have been employed to influence setting time and strength (Satyan, *et al.*, 2023).
2. **Foaming Agent:** A stable foaming agent introduces air voids into the mix, reducing density and enhancing thermal and acoustic insulation properties (Raj, *et al.*, 2020).

3. **Water:** Essential for the hydration process, facilitating the chemical reactions necessary for the cementitious binder to set and harden.
4. **Fine Aggregates or Fillers:** Materials such as sand or industrial by-products are added to improve the density and mechanical properties of the concrete (Raj, *et al.*, 2020).
5. **Fibers:** The incorporation of fibers is pivotal in hybrid foam concrete. Both synthetic fibers (e.g., polyvinyl alcohol (PVA), polypropylene) and natural fibers (e.g., coir) are used to enhance tensile strength, ductility, and impact resistance. Studies have shown that adding 0.3% PVA fiber can increase the tensile strength of foam concrete by 27% compared to control mixes (Satyan, *et al.*, 2023).
6. **Additional Additives:** Pozzolanic materials like fly ash, silica fume, and metakaolin are incorporated to improve durability and strength. Superplasticizers may also be used to enhance workability.

2.3.2.2 Foaming Agents and Process

The generation and stabilization of the foam phase are critical:

Foam Generation Methods: The two primary approaches are the pre-foaming and the inline mixing methods. Both aim to produce a stable foam that can be reliably incorporated into the cement paste. In hybrid systems, ensuring that the foam is compatible with both the hydration reaction and the polymerization process is essential. The uniformity of the pores and preventing premature bubble collapse are major challenges tackled through the optimization of the foaming agent and its concentration (Zhou, *et al.*, 2018).

2.3.2.3 Enhancement through Hybridization

The hybridization process involves combining different types of fibers to leverage their individual benefits and mitigate their limitations. For instance, combining macro-fibers and microfibers can enhance both the tensile strength and ductility of the concrete. Research indicates that hybrid fiber-reinforced concrete exhibits improved mechanical properties due to the synergistic effects of the fiber combinations (Satyan, *et al.*, 2023).

2.3.2.4 Physical and Chemical Characteristics

1. **Microstructure and Porosity**
   i. **Density and Porosity:** The overall density of hybrid foam concrete typically falls in a lower range compared to conventional concrete. With controlled admixture proportions—for instance, formulations containing between 25% to 60% polyurethane—the density can be reduced significantly (from around 1250 kg/m^3 to nearer 1100 kg/m^3), while the porosity

can be tailored to achieve optimal thermal insulation without compromising mechanical strength (Alam, *et al.,* 2017).

ii. **Chemical Reactions:** The dual reactions of cement hydration and polymerization are pivotal. Several studies have employed techniques such as XRF (X-ray fluorescence), XRD (X-ray diffraction), FT-IR (Fourier-transform infrared spectroscopy), and SEM (scanning electron microscopy) to elucidate these processes. These analyses confirm that robust interfacial bonding between the polymer and hydration products (like CSH) contributes both to the structural integrity and the improved thermal performance of the material (Alam, *et al.,* 2017).

2. **Thermal Properties:** One of the notable advantages of hybrid foam concrete is its excellent thermal insulation. The polymeric phase, along with a deliberately designed porous structure, is responsible for reducing thermal conductivity. Experimental investigations have demonstrated that formulations with higher polyurethane content record thermal conductivities as low as 0.0882 W/mK. This attribute, combined with a smart design of the filler material (like the use of RHA), allows the material to efficiently reject infrared radiation, making it well-suited for energy-saving building panels in hot climates (Alam, *et al.,* 2017).
3. **Mechanical and Durability Properties:** The inclusion of fibers significantly influences the mechanical and durability properties of foam concrete

i. **Compressive Strength:** While the primary aim is to enhance tensile properties, certain fiber additions can also contribute to compressive strength improvements. However, the effect varies depending on fiber type and content (Karthik, *et al.,* 2019).

ii. **Tensile Strength and Ductility:** Fibers bridge cracks and provide resistance to crack propagation, thereby enhancing tensile strength and ductility. Hybrid fiber systems, combining different fiber types, have been shown to be particularly effective in this regard (Karthik, *et al.,* 2019).

iii. **Shrinkage and Cracking:** Fibers help control shrinkage cracking by providing restraint against volumetric changes during curing. This leads to improved durability and reduced maintenance needs (Karthik, *et al.,* 2019).

Applications in Construction

Hybrid foam concrete is utilized in various construction applications, including:

i. **Lightweight Structural Elements:** Used in the production of panels, blocks, and other precast elements where reduced weight is beneficial without compromising strength (Satyan, *et al.,* 2023).
ii. **Thermal and Acoustic Insulation:** The inherent properties of foam concrete, combined with fiber reinforcement, make it suitable for insulation purposes in buildings (Satyan, *et al.*, 2023).
iii. **Tunneling and Underground Structures:** Its lightweight nature and improved mechanical properties make it ideal for applications in tunneling, providing ease of handling and installation (Satyan, *et al.,* 2023).

2.3.3 Palm Kernel Oil

Palm kernel oil (PKO), extracted from the seeds of the oil palm tree (*Elaeis guineensis*), is predominantly composed of saturated fatty acids, with lauric acid being the most abundant. This high saturation imparts PKO with unique chemical properties, making it a valuable resource in various industrial applications. In the context of civil engineering, particularly in the development of hybrid foam concrete, the utilization of PKO and its derivatives has garnered attention for their potential to enhance material performance and sustainability.

2.3.3.1 Utilization of Palm Kernel Shells in Concrete

While direct studies on PKO as an additive in foam concrete are limited, extensive research has been conducted on the use of palm kernel shells (PKS), a by-product of the palm oil industry, as lightweight aggregates in concrete. These studies provide insights into the feasibility of incorporating palm oil derivatives into concrete formulations.

For instance, a study published in Case Studies in Construction Materials explored structured mixture proportioning for oil palm shell concrete, demonstrating that PKS can be effectively utilized to produce lightweight concrete with satisfactory compressive strength and durability. Similarly, research presented at the International Structural Engineering and Construction Conference investigated the compressive strength of palm kernel shell concrete, highlighting the material's potential in sustainable construction practices.

2.3.3.2 Potential Benefits in Foam Concrete

The incorporation of PKO or its derivatives into foam concrete could offer several advantages:

1. **Enhanced Water Resistance:** The hydrophobic nature of PKO's fatty acids may reduce the permeability of foam concrete, thereby decreasing water absorption and enhancing durability.
2. **Improved Workability:** PKO could act as a natural plasticizer, improving the flow-ability of the concrete mix without the need for synthetic additives.

3. **Sustainability:** Utilizing PKO aligns with sustainable construction practices by valorizing agricultural by-products, reducing waste, and promoting the use of renewable resources.

2.3.3.3 Feasibility and Challenges

While the theoretical benefits are promising, practical implementation requires careful consideration:

1. **Compatibility:** The interaction between PKO and cementitious materials must be thoroughly investigated to ensure that the chemical reactions do not adversely affect the setting time or strength development of the concrete.
2. **Optimal Dosage:** Determining the appropriate amount of PKO to be used is crucial, as excessive quantities could lead to issues such as delayed setting or reduced mechanical properties.
3. **Long-Term Performance:** Assessing the long-term durability and performance of foam concrete modified with PKO is essential to ensure that benefits such as reduced water absorption translate into extended service life.

CHAPTER THRE

MATERIALS AND METHOD

3.1 Preamble

This chapter explains the material used in the process of gathering the information on the research work and the methods employed in carrying out the findings.

3.2 Materials

The materials used in this research include; Water, cement, fine aggregate (sand), foaming agent, palm kernel oil solvent and water. The materials were gotten from different source to make a success of this research study.

3.2.1 Water

Portable water is used for mixing and curing. A water cement ratio (w/c) of 0.45 is adopted for concrete mix. Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. In practice, very often great control on properties of cement and aggregate is exercise, but the control on the quality of water is often neglected. Since quality of water affects the strength, it is necessary to go into the purity and quality of water.

3.2.2 Cement

The cement to be used in this study is OPC (Grade 42.5) and it will be bought from a reliable retailer shop around Maraba, along Old Jebba way, Ilorin, Kwara State. It will be properly tested to make sure it conforms to BS EN 197 – 1(2011) requirement.

Fig 3.0 Ordinary Portland Cement

3.2.3 Fine Aggregate/ Sand

The fine aggregate to be used in this research will be obtained from a quarry shop around Maraba, along Old Jebba way, Ilorin, Kwara State and will be transported to the Civil Engineering Department Laboratory; Kwara State Polytechnic at the Institute of Technology (IOT). The fine aggregate used will be sieved through a BS 4.75mm sieve to remove some of the contained coarse aggregates.

Fig 3.1 Fine Aggregate/Sand

3.2.4 Foaming Agent

The creation of a stable foam is central to achieving the desired lightweight, porous material. It is a surfactant that stabilizes the air bubbles in the mix. Commonly used synthetic agents help produce a foam with a uniform bubble size. The selected foaming agent will be compatible with both the cement hydration reaction and the polymer-based reactions introduced by the palm kernel oil solvent. Its concentration will be adjusted based on preliminary tests to create a stable and consistent foam.

3.2.5 Palm Kernel Oil Solvent

The unique aspect of this study is the incorporation of palm kernel oil solvent. Understanding its role and properties is crucial:

i. **Chemical Nature:** Palm kernel oil solvent is derived from palm kernel oil, and its properties are influenced by its fatty acid composition. This solvent can reduce surface tension and impart hydrophobicity to local regions of the concrete matrix.

ii. **Purpose:** By modifying the interaction between the cement particles and the foaming agent, it can help adjust the pore structure, altering both the density and water absorption characteristics of the hybrid system.

3.3 Test on materials

3.3.1 Test on Cement

Testing cement is a crucial step in ensuring the quality, consistency, and performance of concrete mixes and construction materials. Various tests are conducted on cement to evaluate its physical, chemical, and mechanical properties according to international standards and specifications.

i. Fineness Test

The fineness test is a crucial assessment conducted on cement to determine the particle size distribution and fineness of its particles. The fineness of cement plays a significant role in its reactivity, hydration rate, setting time, and overall performance in concrete mixes. This test is essential to ensure that the cement meets the required standards and specifications for various construction applications.

Apparatus:

i. **Sieve with 90-micron Opening:** A sieve with a specific opening size of 90 microns (μm) is used to sieve the cement sample and separate the finer particles.

ii. **Air-Permeability Apparatus (Blaine Apparatus):** This apparatus measures the specific surface area of the cement by determining the rate of airflow through a compacted bed of cement particles.

Procedure:

i. **Sample Preparation:** A representative sample of cement is obtained from the bulk material and thoroughly mixed to ensure uniformity.

ii. **Sieve Analysis:** A portion of the cement sample is sieved through the 90-micron sieve to separate the particles finer than 90 microns from the coarser particles.

iii. **Air-Permeability Test (Blaine Test):**

- The Blaine apparatus consists of a permeability cell, a manometer (or pressure gauge), and a vacuum pump.
- The cement sample is compacted in the permeability cell to form a uniform bed of particles.
- A vacuum is applied to draw air through the bed of cement particles, and the rate of airflow is measured using the manometer.
- The specific surface area is calculated based on the rate of airflow and the permeability characteristics of the compacted cement bed.
- The specific surface area is typically expressed in terms of square centimeters per gram (cm^2/g) of cement.

3.3.2 Test on Sand

i. Particle Size Distribution Test

A Particle Size Distribution Analysis (PSD) determines and reports information about the size and range of particles representative of a given material. This analysis can be performed using a variety of techniques; the most suitable will be determined based on the sample properties and question at hand.

The objective of the test is to determine the percentage of individual particle sizes present in a soil sample. Particles size distribution test was done by dry sieving and this method covers the quantitative determination of the particle size distribution in soil down to the fine sand size and the test was done in accordance to BS 1377 of 1961 "Methods of tests for soil for civil engineering purpose"

Apparatus used for particle size distribution test

The apparatus used for sieve analysis test are:

i. Set of sieves
ii. Weighing balance machine
iii. Empty container
iv. Oven

Test procedure

i. 500g of dry aggregate was weighed out of the sample.
ii. Each sieve size was weighed and recorded.
iii. The sample of soil was then poured into the sieves which has a pan at the bottom.
iv. The sieve was shaken manually for ten (10) minutes.
v. The amount of soil retained on each sieve was weighed and the mass was recorded.
vi. The grain curve is then plotted with percentage passing on the ordinate axis and particle size on the co-ordinate axis.

(a) Percentage retained = $\frac{\text{Weight of soil}}{\text{Total weight of sample}}$ x 100%

(b) Cumulative % retained = Sum of percentage retained on all sieves

(c) Cumulative % passing = 100%

ii. Specific Gravity and Absorption

Specific gravity and absorption are important physical properties of aggregates, including fine aggregates used in concrete. These properties provide valuable insights into the density, porosity, and moisture content characteristics of the aggregate, which in turn influence the behavior of concrete mixes (Garcia *et al.*, 2018).

Specific gravity, also known as relative density, is a measure of the density of a material compared to the density of water. In the context of aggregates, specific gravity indicates how dense the aggregate particles are relative to an equal volume of water. It is typically determined by comparing the weight of a given volume of dry aggregate to the weight of an equal volume of water at a specified temperature. Specific gravity values for aggregates usually range between 2.5 to 3.0 for most natural aggregates, with denser materials having higher specific gravity values. Specific gravity is an important parameter in concrete mix design as it affects the yield of concrete per unit volume and helps in estimating the proportion of solid particles in the aggregate (Garcia *et al.*, 2018).

Absorption refers to the ability of an aggregate to absorb moisture, typically expressed as a percentage of the aggregate's weight. This property is determined by immersing the aggregate in water for a specified period and then weighing it in both dry and saturated conditions. Absorption is influenced by the porosity and pore structure of the aggregate, with porous aggregates having higher absorption values. Excessive absorption in aggregates can lead to an increase in the water demand of concrete mixes, affecting workability, strength, and durability. Therefore, controlling absorption is important in ensuring the quality and performance of concrete. Absorption values also play a role in adjusting the water-cement ratio in concrete mix designs to account for the moisture held by the aggregate (Garcia *et al.*, 2018).

Apparatus used for test

i. Pycnometer
ii. Container with water
iii. Weighing scale
iv. Drying pan
v. Graduated cylinder
vi. Desiccator

Test procedure (Specific Gravity Test)

i. Clean and dry the pycnometer thoroughly.
ii. Fill the pycnometer with water and weigh it (W1). Record the weight.
iii. Dry the fine aggregate sample in a drying oven until it reaches a constant weight.
iv. Fill the pycnometer with a known volume of dry aggregate (V).
v. Add water to the pycnometer until it is completely filled, ensuring there are no air bubbles.
vi. Weigh the pycnometer with water and aggregate (W2).
vii. Calculate the specific gravity using the formula:

$$\textbf{Specific Gravity} = \frac{\mathrm{W2} - \mathrm{W1}}{\mathrm{W2} - \mathrm{W1} - \mathrm{V}}$$

viii. Repeat the test with multiple samples to ensure accuracy and repeatability.

Test procedure (Absorption Test)

i. Take a representative sample of fine aggregate and dry it in a drying oven until a constant weight is achieved.

ii. Weigh the dry aggregate sample (W_d).

iii. Immerse the dried aggregate sample in water in a container for a specified duration (usually 24 hours).

iv. Remove the saturated aggregate from the water, drain excess water, and wipe the surface gently with a cloth to remove surface moisture.

v. Weigh the saturated aggregate sample (Ws).

vi. Place the saturated aggregate sample in a drying pan or tray and dry it in the oven until it reaches a constant weight (Wsd).

vii. Calculate the absorption percentage using the formula:

$$\textbf{Specific Gravity} = \left(\frac{W_S - W_{Sd}}{W_{Sd} - W_d}\right) \times 100$$

viii. Repeat the test with multiple samples to ensure accuracy and repeatability.

3.4 Mix Design

Concrete mix design is a crucial aspect of concrete technology that involves selecting the proportions of ingredients to achieve the desired properties in concrete. This process is essential for ensuring the durability, strength, and workability of concrete structures. A well-designed concrete mix not only meets the structural requirements but also considers factors such as environmental conditions, construction practices, and economic feasibility (Olaoye, 2013).

The mix design for hybrid foam concrete incorporating palm kernel oil (PKO) solvent is developed to achieve an optimal balance between strength, density, and water absorption characteristics. Foam concrete is typically composed of cement, fine aggregates (Clean, well graded river sand), water, and a foaming agent. The uniqueness of this lies in the incorporation of PKO either as a partial replacement for water or as a modifying agent in the mix. However, in this study, the conventional cement-sand-water slurry is modified by incorporating palm kernel oil (PKO) solvent, which is hypothesized to alter the microstructure and reduce water permeability. The cement-to-sand ratio will be maintained between 1:2 and 1:3, while the water-to-cement ratio (w/c) will be adjusted within the range of 0.4 to 0.6 to account for the presence of the PKO solvent. The foaming agent will be diluted with water and aerated using a mechanical foam generator until a stable foam is produced.

The preparation process will involve mixing the cement, sand, water (and PKO solvent), and additives thoroughly to achieve a homogeneous slurry. The pre-formed foam will then be carefully blended into this slurry to form the final mix, ensuring even distribution of air voids and any fiber reinforcements. The fresh hybrid foam concrete will be cast into 150 mm^3 cube moulds in three layers, with each layer gently compacted to preserve the integrity of the foam cells. After casting, the specimens will be allowed to set for 24 hours before demolding. The cured samples will then be subjected to water curing at predetermined intervals (7, 14, and 28 days) to simulate standard curing conditions. To assess water absorption, specimens will oven-dried at 105°C until a constant mass is achieved, then immersed in water for 24 hours, and finally weighed to determine the increase in mass. The density will be measured by calculating the ratio of the specimen's mass to its volume. These tests will be repeated for different proportions of PKO solvent to determine its optimal dosage and to understand its effect on both water absorption and density in the hybrid foam concrete.

3.5 Laboratory Testing

In this study, two primary tests; water absorption and density determination will be conducted to evaluate the performance of hybrid foam concrete modified with palm kernel oil solvent (PKO). The water absorption test follows guidelines similar to ASTM C642. This is critical in understanding the material’s pore structure and durability, as highlighted by Banthia and Gupta (2006) and Hassan et al. (2015). Essential apparatus for this test include an electric oven, a water bath or large container, digital weighing scales, and safety equipment such as heat-resistant gloves.

For density determination, the mass and dimensions of the concrete specimens are measured. This test is pivotal in assessing the influence of PKO on the compactness and overall structural performance of the foam concrete, with methodologies supported by research from Chin and Ng (2010) and Kumar et al. (2017). Accurate measurement tools such as calibrated moulds, digital calipers, and precision digital scales are used to ensure the reliability of the results.

3.5.1 Water Absorption Test

The water absorption test is a critical procedure used to assess the durability and porosity of hardened concrete. By measuring the amount of water a concrete specimen absorbs, this test provides insights into the material's resistance to water ingress, which is directly related to its longevity and performance in various environmental conditions. The standard method for conducting this test is outlined in ASTM C642, titled "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete."

Materials/Apparatus (Banthia & Gupta, 2006);

i. **Electric Oven:** Capable of maintaining a constant temperature of 105°C for drying specimens.
ii. **Water Bath or Large Container:** For immersing the specimens completely for 24 hours.

iii. **Digital Weighing Scale:** A precision balance to measure the specimen's mass before and after immersion.
iv. **Specimen Moulds:** Standard cube moulds (100 mm × 100 mm × 100 mm) used for casting the foam concrete.
v. **Protective Equipment:** Heat-resistant gloves and safety goggles for handling hot materials.

Procedures (Banthia & Gupta, 2006);

1. **Specimen Preparation:**
   i. The hybrid foam concrete will be casted into 150mm³ cube moulds in three layers, ensuring each layer is lightly compacted to maintain foam integrity.
   ii. The specimens will be allowed to set for 24 hours before demoulding and then cured in water for designated periods (7, 14, and 28 days).
2. **Drying Process:**
   i. The cured specimens will be removed from the water cure and placed in an electric oven.
   ii. The specimens will be dried at 105°C until a constant mass is reached, as per the ASTM C642 guidelines.
3. **Immersion:**
   i. The specimens will be cooled to room temperature.
   ii. After which each specimen will be immersed fully in a water bath for 24 hours.

4. **Weighing and Calculation:**

   i. After immersion, the specimens are removed, and the surfaces will be gently dried with a soft cloth, and weigh using the digital scale.
   ii. The water absorption will be calculated using the formula below;

$$Water\ Absorption\ (\%) = \frac{(Wet\ weight - Dry\ weight}{Dry\ weight} \times 100$$

   iii. This percentage indicates the degree of water ingress, which is directly linked to the concrete's porosity and durability.

3.5.2 Density Determination

The density determination of hardened concrete is a fundamental procedure that provides insights into the material's quality, strength, and durability. A higher density typically indicates a lower porosity, which correlates with enhanced strength and reduced permeability. The standard method for determining the density of hardened concrete is outlined in ASTM C642, titled "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete."

Materials/Apparatus (Chin & Ng, 2010; Kumar *et al.*, 2017);

i. **Digital Weighing Scale:** For accurate mass measurement of the concrete specimens.
ii. **Calibrated Moulds:** Standard cube moulds (100 mm × 100 mm × 100 mm) to ensure consistent specimen dimensions.
iii. **Measuring Tools:** Digital calipers or a measuring tape to verify the dimensions of each specimen.
iv. **Calculator or Software:** For computing the density based on the measured mass and volume.

Procedures (Chin & Ng, 2010; Kumar *et al.*, 2017);

1. **Specimen Preparation:**
   i. The same set of cured specimens from the water absorption test will be used. Having been properly cured under water for the predetermined durations (7, 14, and 28 days).
2. **Measurement of Mass:**
   i. Each specimen will be weighed using the digital scale to record the mass in kilograms.
3. **Determination of Volume:**
   i. Since the specimens are cast in standard cube moulds, their volume can be calculated by cubing the side length.

$$v = 0.15m \times 0.15m \times 0.15m = 0.0034m^3$$

4. **Density Calculation:**
   i. The density of each specimen will be calculated using the formula:

$$Density\ (kg/m^2) = \frac{mass(kg)}{volume(m^3)}$$

   ii. This data provides insights into the effect of PKO on the compactness and structural performance of the foam concrete.