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Investigation of the Durability of Hybrid Foam Concrete Using Palm Kernel Oil Surfactant under Different Curing Conditions

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ABSTRACT: This study investigates the durability of hybrid foam concrete modified with palm kernel oil surfactant under various curing conditions. As the construction industry seeks sustainable materials, hybrid foam concrete, known for its lightweight and insulating properties, presents a promising solution. The research addresses a critical gap regarding the long-term durability of this material, particularly concerning how natural surfactants, like palm kernel oil, interact with different curing methods. The study comprises an experimental design involving the preparation of concrete samples with a constant concentration of palm kernel oil surfactant (1%) and subjecting them to three curing methods: water curing, air curing, and steam curing. Durability assessments included compressive strength and density measurements at 7, 14, and 28 days. Results indicated that the curing condition significantly impacts the concrete's performance. Water and steam curing yielded superior compressive strength and density compared to air curing. The highest compressive strength of 4.44 N/mm² was achieved under water curing at 28 days. These findings provide valuable insights for optimizing curing protocols to enhance the durability of sustainable foam concrete, promoting its application in modern construction.

KEYWORDS: Foam Concrete, Durability, Palm Kernel Oil, Surfactant, Curing Conditions, Sustainable Construction, Compressive Strength

I. INTRODUCTION

Concrete remains a cornerstone of global construction due to its versatility, strength, and cost-effectiveness. However, conventional concrete presents challenges, including high self-weight and poor thermal insulation. In response to a growing emphasis on energy conservation and sustainable building practices, lightweight concrete, particularly foam concrete, has garnered significant attention [1], [2]. Foam concrete is produced by incorporating air voids into a cementitious matrix, resulting in a material with reduced density, excellent thermal and acoustic insulation, and enhanced fire resistance [3].

Despite its advantages, the durability of foam concrete can be a limiting factor for its widespread application. Its porous structure, while beneficial for insulation, can lead to high water absorption, making it susceptible to degradation from moisture, chemical ingress, and freeze-thaw cycles [4]. To address these durability concerns, researchers have explored various modifications, including the use of surfactants to stabilize the foam structure and improve the material's overall performance. While synthetic surfactants are common, there is a growing interest in natural, biodegradable alternatives. Palm kernel oil, a renewable resource, has shown promise as an eco-friendly surfactant that can enhance foam stability and potentially improve the mechanical properties of the concrete [5].

The long-term performance of any concrete is also critically dependent on the curing process. Curing conditions—specifically temperature and moisture—govern the rate and extent of cement hydration, which in turn dictates the development of the concrete's microstructure and its ultimate strength and durability. Different curing methods, such as standard water curing, air curing, or accelerated methods like steam curing, can lead to significantly different outcomes. For instance, steam curing is often employed in precast applications to accelerate early

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strength gain [6], while negative temperature curing, relevant in cold regions, can impede hydration and compromise frost resistance [7]. Therefore, understanding the interplay between a novel material formulation, such as foam concrete with a natural surfactant, and various curing environments is essential for predicting its in-service performance.

This study investigates the durability of a hybrid foam concrete incorporating a palm kernel oil-based surfactant (PKO-S) when subjected to different curing regimes. The research aims to elucidate how water curing, air curing, and steam curing affect the density and compressive strength development of this sustainable concrete variant. By systematically evaluating its performance, this work seeks to provide practical insights into optimizing curing practices to enhance the long-term durability of PKO-S-modified foam concrete, thereby supporting its adoption in sustainable construction.

II. INNOVATIONS IN FOAM CONCRETE AND CURING TECHNOLOGIES

2.1. Curing Methods and Their Influence on Concrete Properties

The curing process is a critical phase in concrete production, as it directly influences the hydration of cement and the development of the material's microstructure. The choice of curing method can significantly alter the final mechanical properties and durability of the concrete.

- **Standard and Air Curing:** Conventional water curing (submerging in water) or high-humidity environments provide the necessary moisture for cement hydration, typically leading to a dense microstructure and optimal strength development. In contrast, air curing, where concrete is exposed to ambient atmospheric conditions, can lead to rapid moisture loss, incomplete hydration, and the formation of microcracks, thereby reducing strength and durability [8].
- **Steam Curing:** This is an accelerated curing method often used for precast concrete elements to achieve high early strength. The elevated temperature speeds up the hydration reactions. However, it can lead to a coarser pore structure and the formation of micro-cracks if not properly controlled, which may negatively affect long-term durability [6].

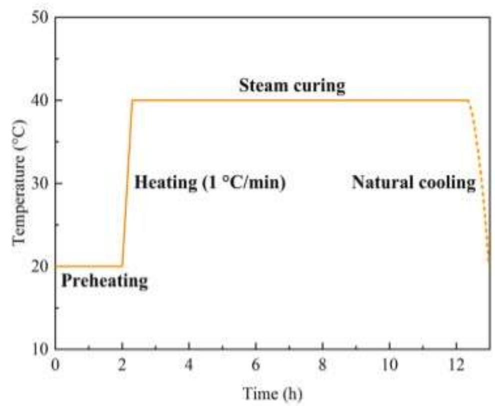

Figure 1: Typical temperature-time curve for steam curing [6].

- **Specialized Curing Conditions:** Other methods like microwave curing [9] and negative temperature curing [7] are being explored for specific applications. Microwave curing offers rapid and uniform heating, potentially enhancing hydration, while negative temperature curing simulates conditions in cold climates, where frost resistance becomes a primary concern.

2.2. Enhancing Durability through Material Design

Beyond curing, the durability of foam concrete can be enhanced through modifications to its composition.

- **Internal Curing Agents:** The use of internal curing agents, such as superabsorbent polymers (SAP) or lightweight aggregates, helps to maintain internal moisture, promoting more complete hydration and reducing shrinkage cracking [10]. This is particularly beneficial in low water-to-cement ratio mixes where self-desiccation can be a problem.
- **Surface Modifications:** Applying protective coatings or impermeable layers is another effective strategy. [NO_PRINTED_FORM] [11] demonstrated that coatings like epoxy and water-based elastomers could significantly reduce water absorption and improve resistance to chemical attack. Similarly, geopolymer mortar layers enhanced compressive strength and abrasion resistance.

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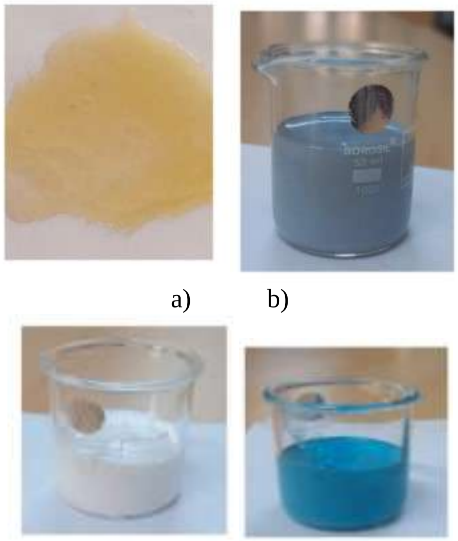

a) b) c) d)

Figure 2: Examples of surface coating materials for enhancing foam concrete durability a) Epoxy resin coating b) Nano water proofing material c) water-based elastomeric coating d) Polymer coating. [11].

- **Sustainable Binders and Aggregates:** Incorporating industrial by-products such as fly ash, slag, or coal gangue can improve the properties of foam concrete. These materials often exhibit pozzolanic activity, reacting with calcium hydroxide to form additional C-S-H gel, which densifies the microstructure and enhances long-term strength and durability [6]. The development of CO_2-ceramsite foam concrete is another innovative approach that combines lightweight aggregates with carbon sequestration, offering both improved mechanical properties and environmental benefits [12].

III. MATERIALS AND EXPERIMENTAL PROGRAM

3.1. Materials

The materials used in this experimental program were sourced locally and characterized to ensure consistency. The primary components included Portland Limestone Cement, fine sharp sand, hybridized stone dust, and the palm kernel oil-based surfactant (PKO-S).

- **Portland Limestone Cement:** Grade 42.5R, conforming to BS EN 197-1:2011 and ASTM C150-20 standards, was used as the primary binder.
- **Fine Aggregates:** Fine sharp sand was sieved through a 1.7 mm mesh in accordance with BS 1377 standards.
- **Coarse Aggregates:** Hybridized stone dust, also sieved through a 1.7 mm mesh, was used as the coarse aggregate component.
- **Surfactant:** A biodegradable surfactant was synthesized from palm kernel oil (PKO-S).
- **Foaming Agent:** A commercially available Sodium Lauryl Sulfate (SLS) was used to generate the foam.
- **Water:** Potable water from the laboratory tap was used for mixing and curing.

Table 1: Chemical Composition of Cementitious Materials and Aggregates

Compound	Cement (%)	Stone Dust (%)	Fine Sand (%)
CaO	62.50	45.30	5.20
SiO_2	21.80	25.10	75.60
Al_2O_3	5.50	12.40	8.90
Fe_2O_3	3.20	8.60	2.10
MgO	2.10	3.20	1.50
SO_3	2.80	0.80	0.50
Others	2.10	4.60	6.20

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3.2. Mix Design and Specimen Preparation

The mix proportion for the hybrid foam concrete was designed with a cement-to-aggregate ratio of 1:2 by weight. The water-to-cement ratio was maintained at 0.75 for all mixes. The PKO-S was added at a concentration of 1% by weight of cement.

Table 2: Mix Proportions for Hybrid Foam Concrete (per m³)

Material	Quantity
Cement	450 kg
Stone Dust	450 kg
Fine Sand	450 kg
Water	337.5 kg
PKO-S	4.5 kg
Foaming Agent (SLS)	As required to achieve target density

The foam was generated using a pre-foaming method. The dry components (cement, stone dust, and sand) were first mixed for two minutes. Water and the PKO-S were then added and mixed for another three minutes to form a homogenous slurry. The pre-formed foam was then incorporated into the slurry and mixed until a uniform consistency and the target plastic density were achieved. The fresh concrete was cast into 150 mm cube moulds for compressive strength testing.

3.3. Curing Regimes

After casting, the specimens were demolded after 24 hours and subjected to three different curing regimes until the testing ages of 7, 14, and 28 days:

- **Water Curing:** Specimens were fully submerged in a water tank at an ambient temperature of 27 ± 2°C.
- **Air Curing:** Specimens were stored in the laboratory under ambient conditions (temperature of 27 ± 2°C and relative humidity of approximately 60-70%).
- **Steam Curing:** Specimens were placed in a steam curing chamber. The temperature was raised to 80°C over 2 hours, maintained for 8 hours, and then allowed to cool naturally.

3.4. Testing Procedures

The durability and mechanical properties of the hardened concrete were evaluated at 7, 14, and 28 days.

- **Density:** The density of the specimens was determined by measuring their mass and volume after curing.

Compressive Strength Test: The compressive strength of the 150 mm cube specimens was tested in accordance with BS EN 12390-3 using a universal testing machine. 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

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figure 3: Weighed Materials before mixing

figure 4: Sieving of Stone dust

Figure 5: Crushing of Concrete Specimen

Figure 6: Removal of Samples After Crushing

Figure 7: Compressive Test Machine

IV. RESULTS AND DISCUSSION

4.1. Density Development

The density of the hybrid foam concrete specimens was influenced by the curing conditions. As shown in Figure 8, the water-cured specimens exhibited the highest density, followed by air-cured and then steam-cured specimens. The density of the water-cured specimens increased from 2127 kg/m³ at 7 days to 2161 kg/m³ at 14 days, before slightly decreasing to 2114 kg/m³ at 28 days. This initial increase is likely due to water absorption and continued hydration, while the slight decrease at 28 days may be related to the development of the internal pore structure. The air-cured specimens showed a more consistent density, while the steam-cured specimens had the lowest density, which is consistent with the accelerated evaporation of water at high temperatures.

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

Table 3: Weight of Specimen Cubes In 7 Days

Days	Curing Method	% Of PKO	Weight(g)
7	Air	1%	7023
		1%	6560
	Water	1%	7101
		1%	7253
	Steam	1%	6800
		1%	6680

Table 4: Weight of Specimen Cubes in 14 days

Days	Curing Method	% Of PKO	Weight(g)
14	Air	1%	7083
		1%	6508
	Water	1%	7215
		1%	7375
	Steam	1%	6640
		1%	6809

Table 5: Weight of Specimen Cubes in 28 days

Days	Curing Method	% Of PKO	Weight(g)
28	Air	1%	6870
		1%	5995
	Water	1%	7377
		1%	6893
	Steam	1%	6101
		1%	6498

Table 6: Average Weight of Specimens for 7, 14 and 28 days

Days	Curing Method	% of PKO	Average Weight(G)
7	Air	1%	6791
	Water	1%	7177
	Steam	1%	6740
14	Air	1%	6796
	Water	1%	7295
	Steam	1%	6725
28	Air	1%	6433
	Water	1%	7135
	Steam	1%	6300

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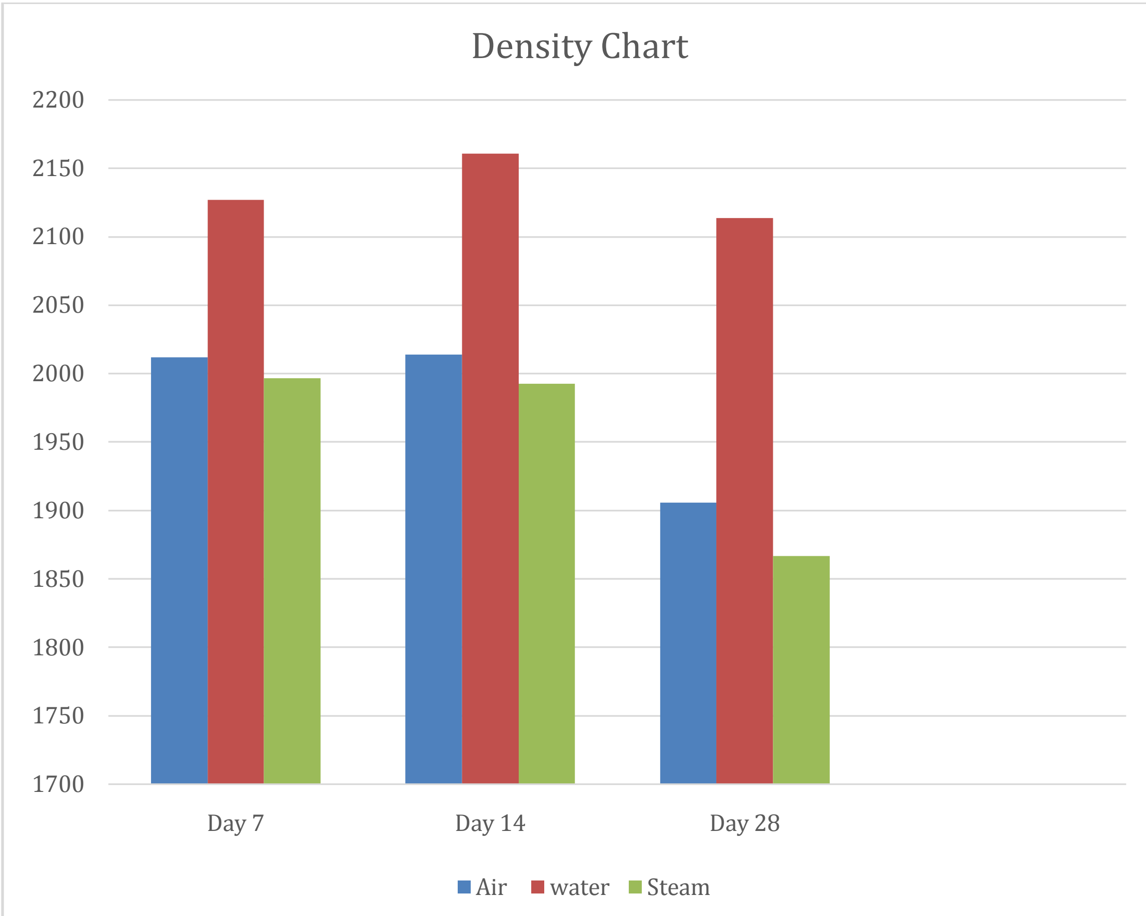

Figure 8: Density chart

From the chat and table, it was derived that the density of hybrid foam concrete increases alongside the curing conditions (air and steam) in relation with the number of curing days, and also it varies for water curing condition it tends to decrease after 14 days.

4.2. Compressive Strength

The compressive strength of the hybrid foam concrete was significantly affected by the curing method, as illustrated in Figure 9, Water curing consistently resulted in the highest compressive strength at all ages, reaching a maximum of 4.44 N/mm² at 28 days. This is attributed to the continuous supply of water, which facilitates a more complete hydration of the cement particles, leading to a denser and stronger microstructure.

Steam curing also yielded high compressive strength, particularly at later ages, reaching 4.13 N/mm² at 28 days. The elevated temperature accelerates the hydration reactions, contributing to rapid strength gain. Air curing resulted in the lowest compressive strength, with a 28-day strength of 3.56 N/mm². This is due to the premature drying of the concrete surface, which halts the hydration process and leads to a weaker, more porous microstructure. The results clearly indicate that providing adequate moisture during curing is essential for achieving optimal durability and strength in PKO-S modified hybrid foam concrete.

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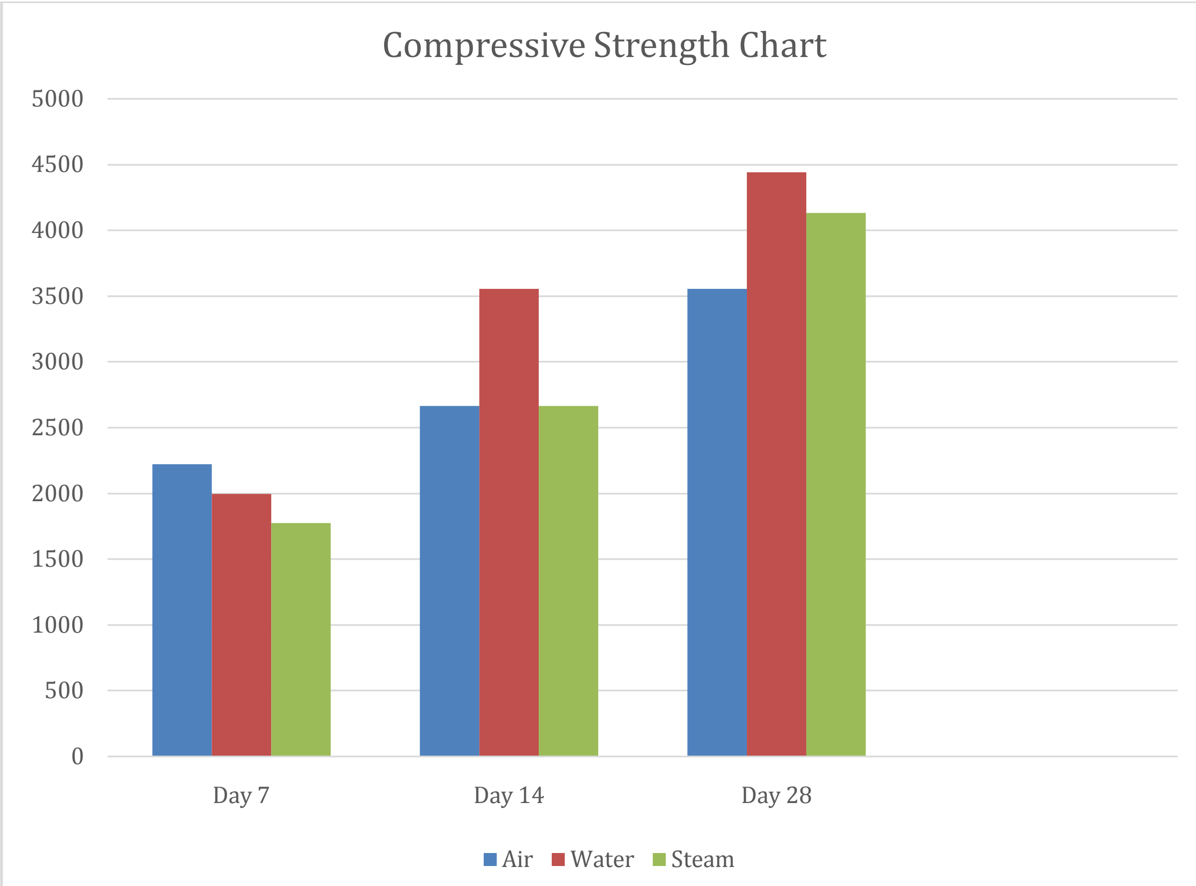

Figure 9: Compressive strength chart

V. CONCLUSION

Based on the results of this study, the following conclusions can be drawn:

1. The durability of hybrid foam concrete incorporating palm kernel oil-based surfactant is highly dependent on the curing conditions.
2. Water curing proved to be the most effective method, resulting in the highest compressive strength and a dense microstructure due to sustained cement hydration.
3. Steam curing also provided significant strength development, making it a viable option for applications requiring accelerated strength gain.
4. Air curing resulted in the lowest strength and density, highlighting the importance of moisture retention for the durability of foam concrete.
5. The use of a 1% concentration of palm kernel oil-based surfactant, in conjunction with appropriate curing methods, can produce a durable and sustainable lightweight concrete suitable for non-load-bearing applications.

VI. RECOMMENDATIONS

- For practical applications, water curing or membrane-forming curing compounds are recommended to ensure the durability of hybrid foam concrete with PKO-S.
- Further research should investigate the influence of different concentrations of PKO-S on the durability of foam concrete under various curing conditions.
- Long-term durability studies, including tests for chemical resistance, carbonation, and freeze-thaw resistance, should be conducted to fully assess the performance of this material.
- A life cycle assessment (LCA) would be beneficial to quantify the environmental advantages of using PKO-S in foam concrete compared to conventional materials and methods.

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