UNIABUJA Journal of Engineering and Technology

https://ujet.uniabuja.edu.ng/

ISSN: 2714-3236 (Online); 2714-3228 (Print)

Volume 2, Issue 1, 2025; 128-140

Durability Performance of Kenaf Fibre Foamed Concrete Produced with Rice Husk Ash as Partial Replacement for Cement

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Abstract

This study investigated the durability performance of kenaf fibre foamed concrete produced with rice husk ash (RHA) as partial replacement of cement. The research investigated foamed concrete with a design density of 1600 kg/m³, cured in water at 7,14, 28, 56, and 90 days. Test conducted on foamed concrete include density, compressive strength, split tensile strength flexural strength, sorptivity, fire resistance and Ultrasonic Pulse Velocity. The maximum compressive strength at 28 days was the control which achieved 14.69 N/mm².while the maximum split tensile strength was 2.41 N/mm² with 0.5% kenaf fibre addition. The fire resistance of foamed concrete reduced as the temperature increases. The strength of foamed concrete at elevated temperature of 400⁰C is minimally reduced. The Ultrasonic pulse velocity decreased with increase in the percentage addition of kenaf fibre. The UPV of all concrete samples fell within 3.0-4.5 m/s for concrete of good quality. The findings of this study also showed that at 0.5% kenaf fibre addition, the tensile property of foamed concrete is significantly improved. Also, the presence of kenaf fibre and rice husk ash increased the permeation properties of foamed concrete. The study concluded that foamed concrete has potential for application in structural lightweight insulating material. RHA is a good pozzolana and can be used to reduce cement and kenaf fibre is also a good reinforcing material in foamed concrete as it increases the tensile performance of foamed concrete.

Keywords: *Compressive strength, fire resistance, kenaf fibre, rice husk ash, ultrasonic pulse velocity, water absorption.*

1.0 Introduction

Designing and constructing energy-efficient buildings is another approach to reducing greenhouse emissions. Concrete is one of the most versatile construction materials, offering potentially unlimited opportunities for developing diverse forms of construction, as its ingredients, namely cement, sand, coarse aggregate, and water, are available all over the globe [1]. In terms of density, concrete can be classified into several types such as lightweight, normal weight, and heavy concrete. [2], mentioned that a reduction in concrete density can be achieved by replacing some of the solid materials in the concrete. The density of the conventional concrete ranges from 2200 to 2600 kg/m³; this weight sometimes makes it uneasy to handle and an uneconomical structural material. Attempts have been made in the past to reduce the self-weight of concrete to increase its efficiency [3]. Based on the aforementioned, effort is being made by researchers to reduce this problem by developing and using lightweight concrete where the quantity of materials like the dense coarse aggregate is fully or partially replaced with lightweight aggregates.

Lightweight concrete possesses strength similar to that of normal-weight concrete [4]. It aids in decreasing the dead load of a structure and increase progress of the building. There are different ways to produce lightweight concrete; one method involves replacing traditional aggregates with those of lower specific gravity, known as lightweight aggregate concrete [5]. Another method is to remove fine aggregates from the mixture, leaving only normal-weight coarse aggregates, which is called no-fines concrete. Additionally, concrete that contains air voids within its cement paste is known as aerated or foamed concrete [5].

Foamed concrete is a lightweight substance made of a mortar with cement, which contains many separate bubbles—making up over 50% of its volume. These bubbles are created through physical or chemical methods where air is added to the mixture or gas is produced inside it [6]. Due to its ability to be produced in a variety of densities, ranging from 300 to 2000 kg/m³, foamed concrete has gained popularity in the construction industry [7] [8]. This material supports sustainability efforts because it does not require coarse aggregates in its production. Furthermore, it allows for the partial or complete substitution of fine aggregates and cement with secondary materials, such as fly ash and rice husk ash [9] [10]. The inclusion of air bubbles gives foamed concrete multiple advantages, making it suitable for use in construction as thermal and sound insulation, as well as a material for filling voids [11]. In instances where additional strength is needed, foamed concrete may be applied in semi-structural roles, including bridge abutments, structural elements, subbases for roads, and floor and roof screeds [10] [12]. Additionally, some uses take advantage of foamed concrete's capacity to absorb energy, such as in vehicle arresting systems on airport runways, targets for ballistic ranges, and crash barriers on roads [6]. [13] has studied how foamed concrete behaves in fire when tested at temperatures reaching 900^{0}C. The study found that foamed concrete performs better in fire conditions than regular concrete. However, the standard fire performance of lightweight foamed concrete with various mix ratios has not been explored, indicating a need for further research. Additionally, there has been insufficient focus on the response of foamed concrete in different fire scenarios, including parametric fire and hydrocarbon fire events. Studies on residual properties of foamed concrete investigating its fire performance is still very limited. During fire exposure, structural element will undergo high temperature variation which will induce internal stresses and variation of bonding. Therefore, though the material is capable of handling fire, after the fire situation foamed concrete properties might be different with the initial state.

Fire performance of material is influenced by the characteristics of the material, thermal properties, mechanical properties, deformation properties and special characteristics of material in fire. Thermal properties influence the heat transfer in the structural element, whereas mechanical properties influence the strength and stiffness variation. Deformation properties together with mechanical properties influence the extent deformation and strains in the structural member [14]. The characteristics of all these materials change with temperature and rely on what the material is made of. Hence to predict fire performance, elevated temperature properties need to be determined [14]. [15] conducted studies on the thermal characteristics of foam concrete when subjected to high temperatures; it was discovered that as the temperature rises, the compressive strength of foamed concrete diminishes. When dealing with foamed concrete, it is crucial to consider moisture transfer. Specifically, one must analyse the movement of moisture in foamed concrete carefully, since too much moisture can lead to carbonation and other forms of deterioration, especially in reinforced concrete components. The ability of concrete to absorb water is directly correlated with the voids created when extra water evaporates, resulting in channels within the concrete material [16]. However, the sorptivity and water absorption parameters, which defines the rate at which water penetrates concrete, appears to be a good indicator of both the permeability nature of concrete and its resistance to corrosive factors [17].

By-products or pozzolanic materials, often considered agricultural and industrial waste, are commonly discarded. However, these wastes can serve as viable or alternative materials in the construction sector [18] [19] [20]. The process of recycling or using the solid waste produced by various agricultural and manufacturing sectors can be very beneficial. Concerns regarding the large amount of waste produced, the need for conserving resources, and the expenses of materials have highlighted the importance of reusing solid waste [18]. Furthermore, the viability of incorporating secondary materials, such as, pozzolanic material in foamed concrete, as well as its potential to be re-used itself at the end of its service life, increases its sustainability potential [21]. Nonetheless, since foamed concrete is usually utilized as a filling material in large quantities, it is essential to observe how it affects sustainable building practices, as the presence of significant amounts of Portland cement may result in elevated levels of CO_2 [21]. To avoid this, design needs must be specified clearly, the lowest possible cement content and foamed concrete density must be employed as well as incorporating secondary materials (e.g., Rice Husk Ash) in the mix. Furthermore, this research aims to examine the use of reinforcement like Kenaf fibre to see if adding it can enhance the qualities of foamed concrete, in light of issues related to strength and cracks.

Hibiscus cannabinus, or kenaf, is a plant of the Malvaceae family that grows in tropical and sub-tropical areas. It is an annual herbaceous plant (or, rarely, a short-lived perennial) growing to 1.5 to 3.5 m tall, with a woody base. The stems are 1 cm to 2 cm in diameter and often but not always branched. The length of the leaves, ranges from 10 to 15 cm, and their shapes vary. The leaves located at the bottom of the stems are deeply lobed, featuring between 3-7 lobes, whereas the leaves found at the top of the stems have a slight lobing [22]. Numerous research works have focused on the mechanical properties of fibre-reinforced foamed concrete [23] [24] [25], but minimal consideration has been given to how incorporated fibres influence the durability performance of the foamed concrete.

2.0 Materials and Methods

2.1 Materials

The primary binder used was Portland Limestone Cement, produced following the guidelines of [26]. Rice husk was sourced from a rice mill located at the Muda-lawal market in Bauchi Metropolis. Kenaf Fibre (KF) was obtained from Ballanga, Gombe State. The fibres were subjected to a bacterial retting operation. The KF was thoroughly cleaned to remove soil particles from the surface, and then dried at room temperature. The fibres were treated because of its hydrophilic properties. Sodium hydroxide was applied to modify the fibres' surface in a process called mercerization. The reagent (NaOH) was purchased from a chemical dealer in Bauchi, Bauchi state Nigeria. These fibres were cut to an adequate size of 50mm size for use in the production of FC. This project utilized river sand sourced from the Yelwa river located in the Bauchi metropolis. Fine aggregate that passes a 300micron sieve but remains on a 150micron sieve is specified in [27]. The reason for this is that larger aggregates can sink in a light mixture and cause the foam to fail while blending. A foaming agent made from protein was utilized to create the foam. The water employed in this task is drinkable tap water. This is important when a protein based foaming agent is used since organic pollutants can negatively affect both the foam's quality and the concrete produced.

2.2 Mix Proportions

A mix ratio was produced to achieve the desired plastic density of 1600kg/m3 (±50kg/m^3), as density was the main design factor with rice husk ash maintained at 10% for all mixes. Currently, there is no established procedure for mixing foam concrete. Hence, to reach the needed density and workability using local materials, tests were conducted in this research. Table 1 shows the mixture proportions for the rice husk ash foamed concrete, while Table 2 details the percent of kenaf fibre included in the mix.

Table 1: Mix Constituents Proportion for the Foam Concrete Mixes

Mix Constituents Proportion for the Foam Concrete Mixes in kg/m^3					
Binder(kg/m^3)		Sand (kg/m^3)	Water for Base Mix (kg/m^3)	Foam Concentration	
Cement	RHA*			Mixing Water (kg/m^3)	Foam (g/m^3)
450.00	50.00	850.00	250.00	12.42	220.80

Table 2: Kenaf Fibre Content

Kenaf Fibre Content (%/Kg)				
	% Kenaf Fibre Addition			
Sample	0%	0.25%	0.50%	1%
Cubes	0	0.003	0.006	0.012
Cylinder	0	0.0048	0.0096	0.0192
Beam	0	0.015	0.03	0.06

2.3 Methods

2.3.1 Preliminary Tests on Kenaf Fibre

The preliminary tests on kenaf fibre were carried out to determine the physical, mechanical properties and chemical composition.

2.3.2 Wet Density Test

The test for the wet density of kenaf fibre reinforced foamed concrete was carried out following [28], which involved measuring the weight of a fresh sample placed in a container with a known weight and volume for each batch before pouring it into a mold. To find the density, the weight difference between the container filled with concrete and the weight of the empty container was divided by the container's volume.

2.3.3 Dry Density Test

The concrete specimens were cured ambient condition, then weighed using the weighing balance to determine the mass of the samples in accordance to [29]. The density of concrete specimen was calculated, using the equation 1.

$$\boldsymbol{D} = \frac{\boldsymbol{M}}{\boldsymbol{V}} \tag{1}$$

where D is the density of the concrete specimen in kg/m^3

M = mass of the specimen in kg

V = Volume of the specimen in m^3

2.3.4 Compressive Strength Test

The study examined the compressive strength of cubes measuring 100 x 100 x 100 mm at different ages: 7, 14, 28, 56, and 90 days, as stated in [30]. Water curing methods was. Specimens were tested in a fully saturated condition right after being taken out of the curing tank using the 200 kN ELE general purpose compressive strength machine. The foamed concrete faced a load at a rate of 120KN/min. For each curing age, three specimens were crushed until failure, and the average result was calculated and then divided by the area of the specimens to determine the compressive strength.

2.3.5 Split Tensile Strength Test

The test for split tensile strength was performed on kenaf fibre reinforced foamed concrete based on the method described in [31]. Cylindrical samples measuring 100 x 200 mm were used. The foamed concrete experienced a loading rate of 120KN/min until it failed using the 200 kN ELE general purpose machine. The calculation for the splitting tensile strength (Ts) is given in Equation 2 below.

$Ts = \frac{2F}{\pi \times L \times d}$ ……………………….. (2)

Where: F is the maximum load in (KN), L is the length of specimen in (mm), d is the diameter of specimen in (mm), The split tensile strength is expressed to the nearest 0.05 MPa.

2.3.6 Flexural Strength Test

The flexural strength, also known as the modulus of rupture, of foamed concrete reinforced with kenaf fibre was measured using an unreinforced beam that underwent point loading using the 150 kN flexural universal testing machine. The beam samples were made, set up, and evaluated following guidelines by [32]. The test samples were beams measuring 100 x 100 x 500 mm and were assessed under a single point loading method. The flexural strength (Mr) can be calculated using Equation 3 as:

$Mr = \frac{PL}{bd^2}$ ……………………… (3)

Where: b = measured width in "mm" of the specimen, d = measured depth in "mm" of the specimen, L = length in "mm" of the span on which the specimen was supported, P = maximum load in "kg" applied to the specimen.

2.3.7 Fire Resistance

This experiment was carried out in line with the guidelines of [33]. This experiment was carried out in line with the guidelines of [33]. The foamed concrete samples were examined at 28 and 90 days. These concrete cube samples were exposed to high temperatures of 200, 400, 600, and 800^{0}C for 2 hours, with a heating rate of 10^{0}C per minute. Once the samples had been exposed to the high temperatures, they cooled down naturally to room temperature before undergoing a compressive strength test.

2.3.8 Ultrasonic Pulse Velocity (UPV) Test

This technique utilized information from reference [34], where the duration for a pulse to travel through the concrete sample was documented. Two transducers were positioned on opposite surfaces of the cube sample. A portable ultrasonic nondestructive digital tester (PUNDIT) was employed, which includes a pulse generator, two transducers (one for sending and one for receiving), an amplifier, a timing circuit, a display unit for the time, and connecting wires. In this testing method, the transducer generates an ultrasonic pulse while it is in contact with one side of the concrete element being evaluated. After moving through a predetermined distance (L) in the concrete, the vibration pulse is transformed into an electrical signal by the other transducer that is in contact with the opposite side of the concrete element, and an electronic timer measures the transit time (T) of the pulse. Foamed concrete samples were examined at 7, 28, and 90 days. The pulse velocity (V) is determined using equation 4.

$Velocity\ (\frac{m}{s}) = \frac{L}{T}$ - 4.

Where L = distance between centers of transducers faces (m)

T = transit time (s)

2.3.9 Water absorption test

After the specified curing period, the foamed concrete cubes were put into an electronic oven set at 105 degrees Celsius for a duration of 72 hours. Once the drying was complete, the samples were taken out to cool down to room temperature before being weighed to find their initial weights (W_1). After being soaked in the curing solution for 30 minutes, the concrete samples were taken out, dried with a cloth, and then weighed again to record their final weights (W_2). The gathered data was documented, and calculations were performed to evaluate the absorption rate of the concrete samples, following the method outlined in [35]. Tests on the foamed concrete specimens were conducted at intervals of 28, 56, and 90 days. To determine the absorption capacity of the specimens, Equation 5 was applied.

$WA = \frac{W2 - W1}{W2}\ x\ 100\%$ ……………………… (5)

2.3.10 Sorptivity test

The measurement of capillary rise absorption was used to determine the sorptivity on fairly uniform material. Water served as the fluid for testing, and assessments were conducted at intervals of 28, 56, and 90 days. The specimen was dried in an oven set at a temperature of 10^0 ± 10^{0}C. It was then submerged in water, ensuring the water level did not exceed 5 mm above the specimen's base. To prevent water flow from the outer surface, a non-absorbing sealant was applied, using either Abro Sealant or Silicon Sealant as a coating.

The amount of water absorbed was measured within time slots of 10 minutes, 15 minutes, and 20 minutes by weighing the specimen on a digital scale. Any excess water on the specimen was removed with a damp tissue, and each weighing was completed in under 30 seconds. Sorptivity, represented as S, indicates how likely a porous material is to absorb and transfer water through capillary action. The total amount of water absorbed per unit area of the surface increases in relation to the square root of the time that has passed (t). The results were derived using equation 6:

$$S = \frac{I}{t1/2} \text{ - - - - - - - - - - - - - - - - - - - } (6).$$

Where, S = sorptivity in mm
T = elapsed time in minutes
I = Δw/Ad
Δw = change in weight = W_1 – W_2
W_1 = Oven dry weight of cubes in grams
W_2 = weight of cube after successive minutes' capillary suction in grams
A = surface area of the specimen through which water penetrated
d = density of water

3.0 Results and Discussions

3.1 Physical and Chemical Composition of Kenaf Fiber

Table 3 shows the physical and chemical properties of the treated Kenaf fibre. The diameter of fibre is 83.24μm, the density is 1200 gr/cm^3, specific gravity is 1.07, elastic modulus 41.21 GPa, tensile strength is 708.22 MPa while the elongation at yield is 1.65. The finding of this research is close to that of [36] who reported that Kenaf fibre has a density of 1202gr/cm^{3}elastic modulus of 39.77, tensile strength of 704 MPa and diameter of 65.40 μm.

The result also shows that that kenaf fibre contain 42% cellulose, 22.1% hemicellulose, 8.42% lignin and 2% pectin. The finding of this research is close to that of [37] [38] who reported that the chemical composition of Kenaf fibres consists of cellulose (56–64 Wt. %), hemicellulose (21–35 Wt. %), lignin (8–14 Wt. %) and small amounts of extracts and ash. Also, Findings from [39] [40] showed values ranging from 60–80% cellulose, 5–20% lignin (pectin), and up to 20% moisture. Furthermore, [41] affirmed that kenaf bast fibre contains (cellulose 55%, ash 5.4% and lignin 14.7%).

Table 3: Physical and chemical properties of kenaf fibre

Physical Properties		Chemical Properties	
Diameter (μm)	83.24 um	Cellulose (%)	42.0
Density (gr/cm^3)	1200	Hemicellulose (%)	22.1
Specific gravity	1.07	Lignin (%)	8.42
Water absorption (%)	10%	Pectin (%)	2.00
Elastic Modulus (GPa)	41.21		
Tensile Strength (MPa)	708.22		
Elongation at yield (%)	1.65		

3.2 Wet Density

Table 4 shows the wet density of kenaf fibre foamed concrete produced with rice husk ash as partial cement replacement. The plastic density varied between 1590 to 1635 kg/m^3, there was a small variation within the values recorded from foamed concrete produced and the target density of 1600 kg/m^3. The plastic density of the various concrete mixes decreased as the fibre fraction volume in the mix increases. This is anticipated as the density of kenaf fibre is (1200 kg/m^3) which is low relative to density of the designed foamed concrete. The bio kenaf fibre reduces the density of foamed concrete as the fibre increases in the mix, this can be attributed to the hydrophilic nature of the fibre material which tends to absolve water from the surrounding concrete mix. It also shows that the mixture containing 1.0% KF has the lowest plastic density, which has a reduced density of 2.8% as compared to the control blend with no fibre.

Table 4: Average wet density in (kg/m^3) of fibre reinforced foamed concrete

% Addition of kenaf fibre	Actual Plastic Density (kg/m^3)
0	1635
0.25	1615
0.5	1610
1.0	1590

3.3 Dry Density of Kenaf Fiber Reinforced Foamed Concrete

The impact of kenaf fibre on the dry density of foamed concrete is illustrated in Figures 1. It is evident that as the amount of kenaf fibre in the mix rises, the dry density of foamed concrete drops for all curing durations, both for specimens cured with water and those exposed to air. After 7 days of curing, the dry density decreased as the percentage of kenaf fibre in the foamed concrete increased. The densities of the foamed concrete after 28 days of curing measured at 1680 kg/m3, 1665 kg/m^3, 1660 kg/m^3, and 1640 kg/m^3, corresponding to 0, 0. 25, 0. 5, and 1% of kenaf fibre with a 10% cement substitution using rice husk ash (RHA) across all concrete mixes. A similar pattern was noted for the 90day curing period.

The changes in foamed concrete density can be attributed to the fact that both kenaf fibre and rice husk ash have a lower specific gravity than cement. This lower specific gravity contributes to a reduced density [42] [43] [44]. Therefore, a higher volume of kenaf fibre results in lighter concrete. This phenomenon is also related to the hydrophilic nature of kenaf fibre; as the fibre content increases, it requires more water from the surrounding concrete mix. Although treating the fibre with sodium hydroxide (NaOH) lowers its water absorption demand, it still absorbs a certain percentage of water, as reflected in the results. The noticeable absorption characteristic of kenaf fibre is apparent right after the concrete is poured. Moreover, the dry density of foamed concrete with kenaf fibre grows as the curing period extends, although the increase follows a nonlinear pattern.

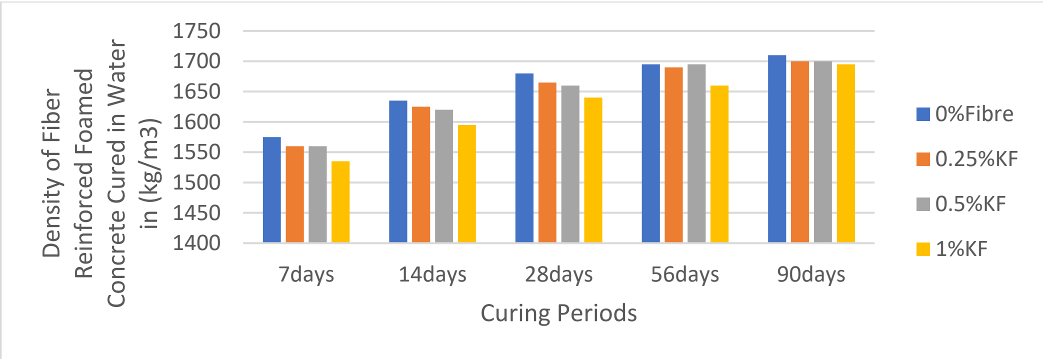

Figure 1: Dry Density of Kenaf Fibre reinforced foamed concrete

3.4 Compressive Strength of Kenaf Fiber Reinforced Foamed Concrete

The compressive strength of kenaf fibre foamed concrete made produced at a density of 1600 kg/m^3, with 10% rice husk ash as a partial replacement for cement, at varying curing periods of 7, 14, 28, 56, and 90 days, is shown in Figure 2. The results reveal that all samples with kenaf fibre exhibited lower compressive strengths than the control samples at every measured curing age. According to Figure 4, the compressive strengths after 7 days of curing measured 8.16 N/mm^2, 8.11 N/mm^2, 8.15 N/mm^2, and 8.11 N/mm^2 for the specimens with 0, 0.25, 0.5, and 1% kenaf fibre, respectively, which indicates reductions in strength of 0.61%, 0.12%, and 0.61% compared to the control sample.

In contrast, the compressive strength of the foamed concrete for the 0% control at 28 days was recorded at 14.69 N/mm^2. After curing for 56 days, the compressive strength for the control samples reached 16.11 N/mm^2, while at 90 days, it increased to 16.23 N/mm^2. This indicates a strength increase of 8. 81% compared to the 28day results. Additionally, the strength at 90 days also shows a 9. 49% improvement in comparison to the 28day strength. This suggests that the formation of CSH gel from cement hydration occurs as the curing age extends. It is important to note that the reduction in strength with the addition of kenaf fibre up to 1% is minimal. However, the development of strength from the inclusion of up to 1% kenaf fibre in foamed concrete allows it to be categorized as structural lightweight concrete [45]. The sufficient availability of water and the high reactivity of the rice husk ash were key factors promoting the RHA reaction during the concrete's hydration process. The lower compressive strength in fibrous mixtures might be due to reduced pozzolanic activity, especially in the younger samples, as well as voids in the foamed concrete. The incorporation of kenaf fibre may also influence the pore structure of the concrete, alongside the weaker interfacial bonds between the natural fibre and the pozzolanic particles within the mix.

Received: 02-01-2025 / Accepted: 01-03-2025 /Published: 31-03-2025

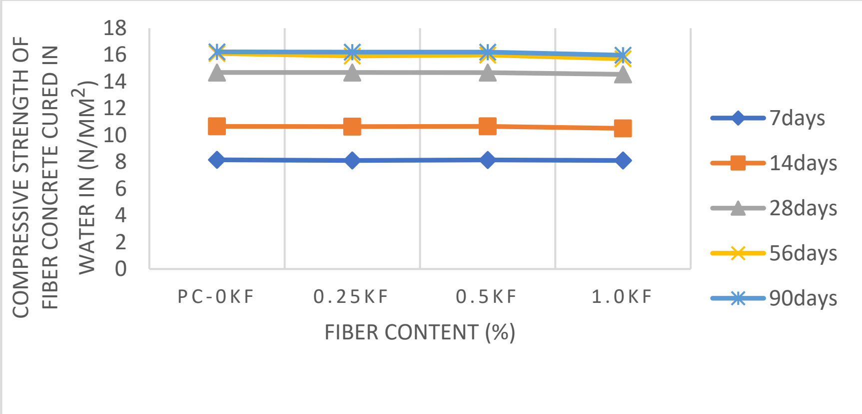

Figure 2: Compressive strength of Kenaf Fibre foamed concrete

3.5 Split Tensile Strength of Kenaf Fiber Foamed Concrete

The findings from the study on the split tensile strength of foamed concrete containing kenaf fibre at a design density of 1600 kg/m^3 with 10% RHA are shown in Figures 3. It was found that the splitting strength improved with curing time across all amounts of added kenaf fibre. Additionally, there was a rise in tensile strength with increased kenaf fibre content in the foamed concrete, peaking at 1% kenaf fibre, where the best performance was noted at 0.5% addition. After 28 days of curing, the tensile strengths recorded were 1.54 N/mm^2, 1.78 N/mm^2, 2.41 N/mm^2, and 1.85 N/mm^2 for the 0%, 0.25%, 0.5%, and 1% kenaf fibre additions, respectively. The lowest tensile strength observed was 1.54 N/mm^2 with no kenaf fibre added, which is similar to the value of 1.8 N/mm^2 found previously for the same density by [46]. The decrease in splitting strength when compared to the control may be attributed to a weak bond between the cement paste and the sand grains. The results of this research surpassed the minimum value of 0.17 N/mm^2 set by ASTM C869 [47], for lightweight concrete.

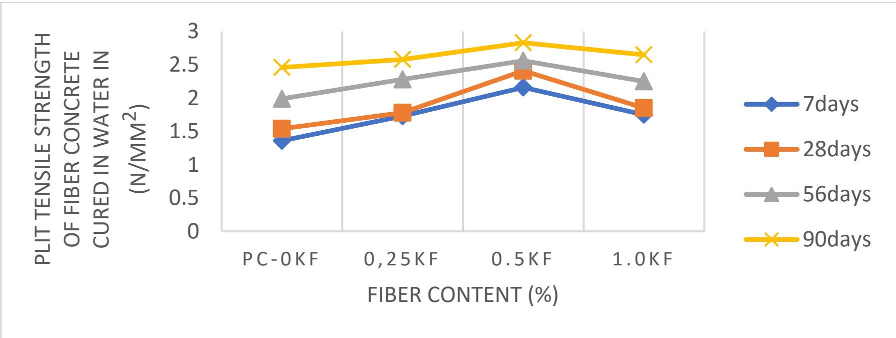

Figure 3: Split strengths of fibre foamed concrete

3.6 Modulus of Rupture of Specimen Cured in Water

Figure 4, present flexural strength of kenaf fibre foamed concrete with design density of 1600 kg/m^3 produced with 10% RHA. It is observed that the flexural strength increased with curing age at all kenaf fibre addition, and also shows an increased in strength as the kenaf fibre content increased in foamed concrete up to 1%, with optimum fibre content at 0.5% kenaf fibre addition. At 28 days of curing, flexural strength achieved was 2.46 N/mm^2, 2.82 N/mm^2, 2.93 N/mm^2, and 2.72 N/mm^2 for 0, 0.25, 0.5, and 1% KF addition respectively at 28 days. At 28days with 0.5%, shows increase in strength of 16.04% as compared to control concrete, which is the optimum. Same trend was observed for concrete at 90days. The strength achieved from this study was comparable to that obtained by [9] for the same density.

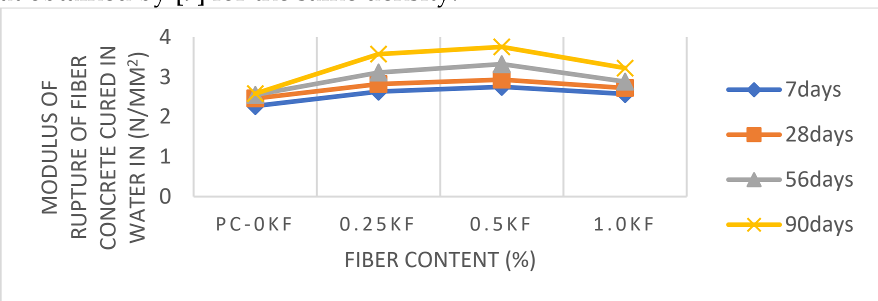

Figure 4: Flexural strengths of fibre foamed concrete

Received: 02-01-2025 / Accepted: 01-03-2025 /Published: 31-03-2025

3.7 Fire Resistance of Fiber Foamed Concrete of Specimens Cured in Water

Figures 5 and 6 shows the typical development of compressive strength for fibre reinforced foamed concrete produced with rice husk ash and thermally treated at 200, 400, 600 and 800°C. It was observed that compressive strength of up to 1% kenaf fibre addition retained its strength marginally with temperature up to 400°C and gradually decline from 600 °C up-to 800 °C. From the result presented it showed that at 200 °C the foamed concrete at all kenaf addition level of 0, 0.25, 0.5, and 1%, achieved compressive strength of 10.25 N/mm², 10.16 N/mm², 10.11 N/mm², and 9.79 N/mm² respectively. At 400 °C the foamed concrete at all kenaf percentage addition of 0, 0.25, 0.5, and 1%, achieved compressive strength of 7.88 N/mm², 7.66 N/mm², 7.59 N/mm², and 7.52 N/mm² respectively. At 600⁰C the foamed concrete at all fibre percentage addition 0, 0.25, 0.5, and 1%, achieved compressive strength of 6.22 N/mm², 6.15 N/mm², 6.11 N/mm², and 5.82 N/mm² respectively. At 800 °C the foamed concrete at all fibre percentage addition of 0, 0.25, 0.5, and 1% achieved compressive strength of 3.43 N/mm², 3.38 N/mm², 3.26 N/mm², and 3.11 N/mm² respectively, it can be seen that the control concrete resist fire better than other fibre percentage addition at 28 days curing period.

At 90 days curing period the compressive strength of concrete at elevated temperature for 200⁰C at all kenaf percentage addition level of 0, 0.25, 0.5, and 1% achieved compressive strength of 10.91 N/mm², 10.84 N/mm², 10.69 N/mm², and 10.45 N/mm² respectively. At 400⁰C the foamed concrete at all kenaf percentage addition level of 0, 0.25, 0.5%, and 1% achieved compressive strength of 8.38 N/mm², 8.29 N/mm², 8.21 N/mm², and 8.13 N/mm² respectively. At 600⁰C the foamed concrete at all kenaf percentage addition level of 0, 0.25, 0.5, and 1% achieved compressive strength of 6.36 N/mm², 66.31 N/mm², 6.18 N/mm², and 5.91 N/mm² respectively. At 800⁰C the foamed concrete at all kenaf fibre addition level of 0, 0.25, 0.5, and 1% achieved compressive strength of 3.85 N/mm², 3.81 N/mm², 3.65 N/mm², and 3.48 N/mm² respectively, it can be seen that the control concrete resist fire better than other kenaf percentage addition at 90 days curing period. The result shows that under elevated temperature kenaf fibre foamed concrete withstand pressure and still performance under strength test, which shows that foamed concrete is a good thermal insulating material. Also, under elevated temperature Foamed concrete still possess sufficient strength.

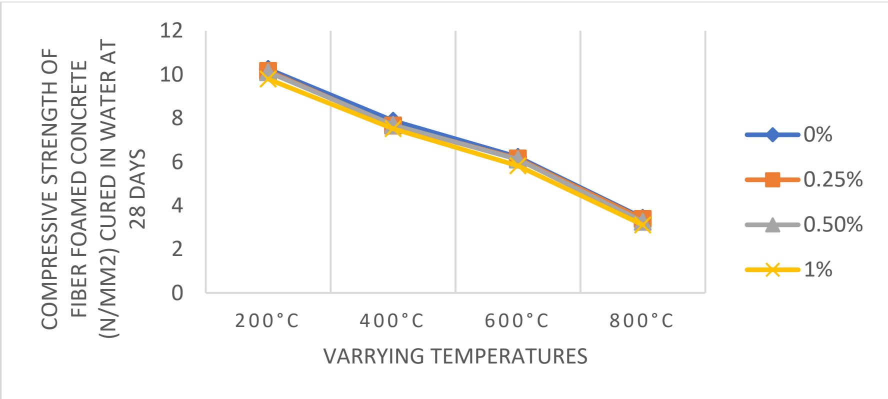

Figure 5: Fire Resistance of fibre foamed concrete at 28 days

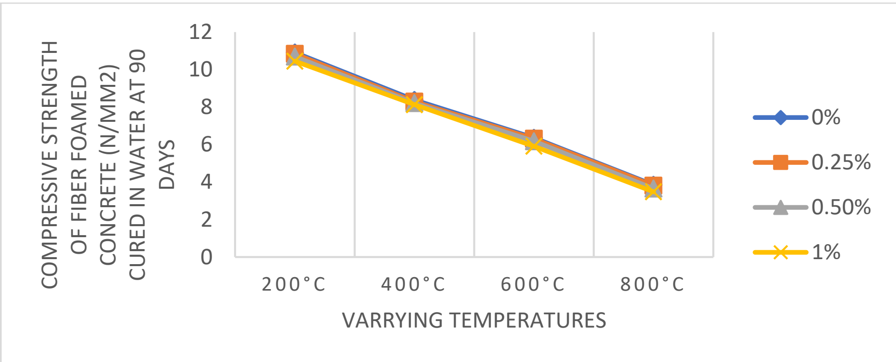

Figure 6: Fire Resistance of fibre foamed concrete at 90 days

3.8 Result of Ultrasonic Pulse Velocity Test of Fiber Foamed Concrete Cured in Water

The ultrasonic pulse velocity (UPV) values for all mixes are shown in Figure 7. The UPV values of all kenaf fibre foamed concrete mixes produced with percentage rice husk ash as partial replacement of cement are quite close to the UPV values of control foamed concrete at all ages. Foamed concrete at 7 days has a UPV within the range of 3.38 to 3.51 m/s, at 28 days foamed concrete has a UPV within the range of 3.82 – 3.98 m/s, while at 90 days foamed concrete has a UPV of 3.9 0– 4.11 m/s. The UPV values at the age of testing showed that all the mixes attained the minimum required value specified for good quality concrete. In addition, the trend of UPV values showed that there is an increase of 13.98% at the age of 90-day compared to the 7-day average values. [48] [49], UPV of 3.00 m/s is considered of good quality and that greater than 4.5 m/s is considered of excellent quality, while below 3.0 m/s is considered of low, poor and questionable quality.

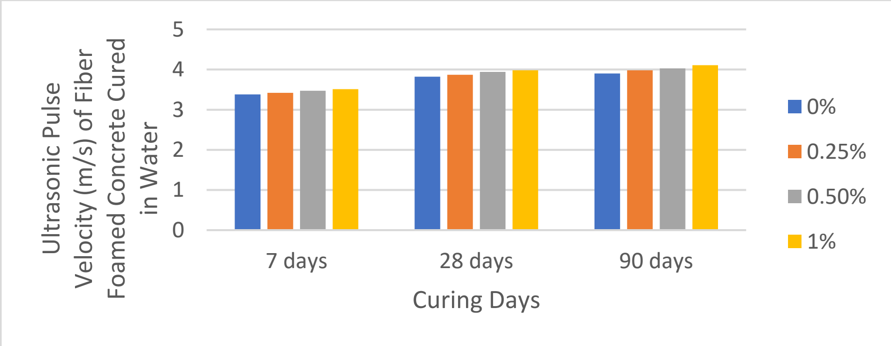

Figure 7: Average Ultrasonic pulse velocity of Kenaf Fibre foamed concrete

3.9 Average Water Absorption Test of Kenaf Fiber Foamed Concrete

Figure 8 presents the water absorption test of kenaf fibre foamed concrete tested at 28, 56 and 90 days', hydration periods. At 28 days, 1% kenaf fibre in concrete absorbed more agent than the control concrete and other percentage fibre inclusion, while control concrete absorbed less as compared to all kenaf fibre addition. Control concrete samples absorbed 2.46% curing agent, while 0.25%, 0.5%, and 1% addition of kenaf fibre absorbed 2.54%, 2.64%, and 2.72% respectively.

The result shows that that kenaf fibre addition with 1% absorbed more amount of agent than control and all other kenaf fibre addition which can be attributed to the presence of high volume of fibre material which tend to absorb more water in the concrete specimen. Water absorption is affected by the concrete mixture proportions, duration of curing and type, age or degree of hydration, existence of micro-cracks and the entrained air content [50] [51]. Foamed concrete shows less water absorbing capacity, this might be as a result of the saturated nature and water generally present in the sample before subjected it to the test.

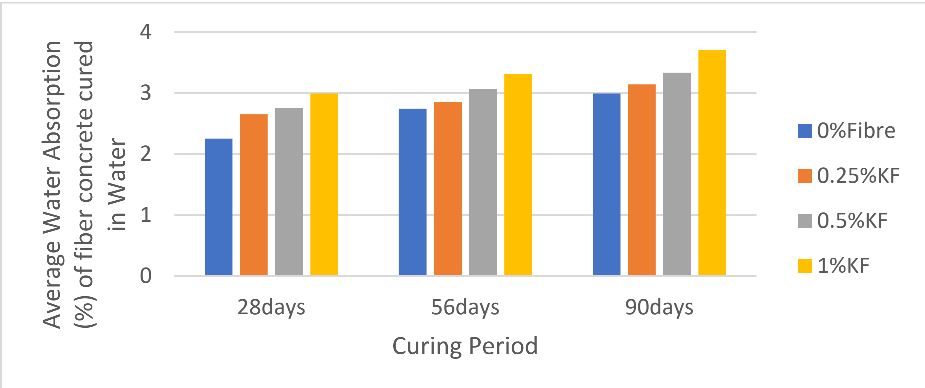

Figure 8: Water absorption test of foamed concrete with fibre cured in water

3.10 Sorptivity of Foamed Concrete

Figure 9, 10, and 11, presents the plot of the cumulative sorptivity against time for kenaf fibre foamed concrete specimens produced with RHA as cement replacement at 10% at 28days, 56 days and 90 days. Table 3, also shows the sorptivity of foamed concrete at 28 days of curing. Sorptivity values for increases with increase in kenaf fibre content. The control foamed concrete has a value of 9.0 x 10^{-8} mm/min$^{0.5}$. 0.25% has a value of 9.8 x 10^{-8} mm/min$^{0.5}$, 0.5% has a value of 11.6 x 10^{-8} mm/min$^{0.5}$, while 1% sorptivity has a value of 11.1 x 10^{-8} mm/min$^{0.5}$ at 28 days. The value of sorptivity from this study is closed to those obtained by [52]. This implies that kenaf fibre increases the sorptivity of concrete, hence, increasing the ingress of water which could affect the durability of the concrete negatively. The higher the percentage of kenaf fibre the higher the sorptivity. In addition, higher curing age leads to reduction in sorptivity. The sorptivity value in subsequent month that is after 56 days of measurements does not considerably differ from the value after 90 days, in cases of lower fibre addition levels up-to 0.5%. The void in foam concrete aid sorption in foamed concrete, rice husk ash also creates voids to allow for ease of water movement. Even though, 0.25 and 0.5% kenaf fibre addition in foamed concrete absorbed less as compared to higher fibre content, although not significantly high when compared with the value of control concrete.

Table 5: Sorptivity of Kenaf Fibre Foamed Concrete at 28 days

% Addition of KF	W2 – W1	A*d x 10^6	I x 10^6	Sorptivity x 10^{-8} mm/min$^{0.5}$
0%	27.1	10	2.71	9.0
0.25%	29.5	10	2.95	9.8
0.5%	31.8	10	3.18	10.6
1%	33.2	10	3.32	11.1

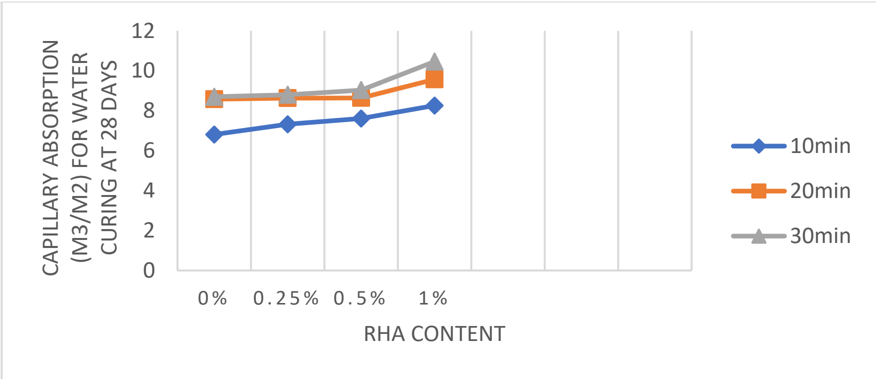

Figure 9: Sorptivity test of Kenaf Fibre Foamed Concrete at 28 days

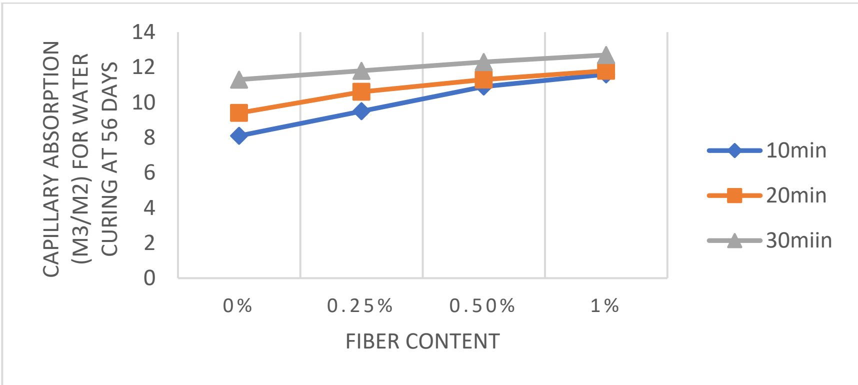

Figure 10: Sorptivity test of Kenaf Fibre Foamed Concrete at 56 days

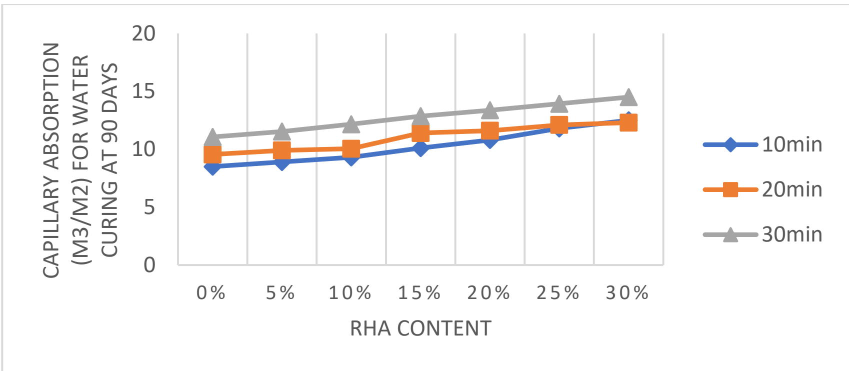

Figure 11: Sorptivity test of Kenaf Fibre Foamed Concrete at 90 days

4.0 Conclusion

This study investigated the performance of kenaf fibre foamed concrete produced with rice husk ash as partial replacement for cement. Kenaf fibre has significant effect on the foamed concrete properties, as the percentage fibre is increased, the density of the foamed concrete is reduced, which makes the specimen lighter in weight. The 28-days compressive strength of 14.69 N/mm² obtained for foamed concrete in this study at the designed density of 1600 kg/m³ is around the minimum strength requirement for classification as a structural lightweight of 15 N/mm² as per standard. The highest split tensile strength of foamed concrete at 28 days was 2.41 N/mm², at 0.5% kenaf fibre addition. The density of the foamed concrete has impact on the sorption performance of the concrete. Water absorption is higher in concrete produced with higher percentage of kenaf fibre. Kenaf fibre foamed concrete show high absorption and sorptivity rate as compared to the control concrete with optimum addition at 0.5%. Up to 1% kenaf fibre addition and 10% RHA as cement replacement can be used in the production of foamed concrete without losing its classification as lightweight concrete. The use of kenaf fibre and rice husk ash in the production of foamed concrete will help improve strength and tensile performance of foamed concrete, it will also encourage the usage of natural fibre materials in concrete production, and help in the reduction of the amount of cement used in concrete production. The compressive strength of foamed concrete is reduced when subjected to higher elevated temperature of 600^oC and 800^oC. The inclusion of kenaf fibre resulted in increased permeability as compared to the controlled samples. The value of the UPV reduced as the fraction of kenaf fibre increases. The optimum kenaf fibre addition was 0.5% observed from the tensile performance of kenaf fibre foamed concrete. It can therefore be concluded that rice husk ash in foamed concrete is a very good pozzolana which can attain a good strength and durability values, however, the increased ingress of moisture into foamed concrete, at 10% partial replacement will not be of great concern.

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Received: 02-01-2025 / Accepted: 01-03-2025 /Published: 31-03-2025