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Strength Predicting Model for Foamed Concrete Produced with Rice Husk Ash as Partial Cement Replacement

Agboola Shamsudeen Abdulazeez [1,*], **Shabi Moshood Olawale** [1], **Aliyu Zakari** [2], **Musa Abdulhakeem Kolawole** [1], **Ridwan Abdulsalam Abiodun** [1], **Bukar Aliyu** [1]

[1]Department of Building and Quantity Surveying, Faculty of Environmental Sciences, University of Abuja, FCT. Abuja, Nigeria
[2]Department of Architecture and Industrial Design, Faculty of Environmental Sciences, University of Abuja, FCT. Abuja, Nigeria

ABSTRACT

Foamed concrete (FC) is a lightweight concrete that can be designed to meet specific strength or density criteria. Foamed concrete with an efficient design, guarantees the desired qualities of durability and strength to be attained. This study aims to predict the compressive strength of foamed concrete produced with rice hush ash as cement partial replacement at 5-30%, using the strength-porosity prediction model with a density of 1600 kg/m3. In order to create the model, a relationship between strength and porosity characteristics was used. The fundamental constant was also found using the numerical analysis bisection method. The characteristics of the fundamental component materials and density that influence the hardened state are examined in this study to investigate the characteristics of foamed concrete. Based on the validity of the results, it can be deduced that the model is appropriate for a laboratory-tested sample of foamed concrete made using rice husk ash as partial cement replacement. Strength-porosity model correlates well with the laboratory-measured strength as it employs the composition of constituents. It is however clear that a strength prediction model can be produced through a selection of criteria such as density, material characteristic properties and proportions to suit different purposes of use and application.

Keywords: Compressive strength, Design density, Foamed concrete, Strength-porosity, Rice husk ash.

1. INTRODUCTION

Concrete is a stone-like substance consisting of aggregate phases of both fine and coarse aggregate, cement, and water. It is a complex material consisting of a binding medium mixed with aggregate fragments. The binding medium is formed by mixing hydraulic cement and

*Corresponding author
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water. Concrete has numerous desirable properties of the major characteristic of concrete is its ability to be transported to a long distance for placement and still maintain its properties. This quality makes it a desirable building material because it can be produced in different forms and shapes with varying properties **(Amran et al., 2015**; **Surahyo, 2019)**. Concrete gives a variety of different performance characteristics, textures, and colors, and is used in special structures, such as buildings, highways, bridges, dams, airports, farm buildings, ponds, breakwaters and irrigation structures, piers, sidewalks, silos, and docks **(Li et al., 2022; Feizbahr and Pourzanjani, 2024).** Concrete is known for its functional performance such as durability, strength, and economic importance **(Agboola et al., 2020a)**. Concrete has undergone development over the last few decades as a result of the addition or substitution of one or more of its primary ingredients with materials that improve its qualities and give it distinctive features **(Rahmat et al., 2024; Ndahi et al., 2024)**.

One kind of such concrete is foamed concrete, it is created without the use of coarse aggregate. Rather, air bubbles are added to the mixture or light aggregate is used to produce it. To manufacture foamed concrete, a mixture of fine aggregate, cement, water, and specific foam is used. It creates a robust, lightweight substance that can be utilized for a variety of purposes once it has solidified **(Shah, 2021; Yang et al., 2023)**. Foamed concrete can be made by reacting aerating chemicals with the cement to form air voids or by adding a foamed agent to the mixture to form pores in the concrete. A separately created foam is combined with cement paste (slurry or mortar) to create foamed concrete, “a lightweight material” **(Pizon, 2023; Lim et al., 2022)**. Its composition is limited to fine sand, cement, water, and foam, with the option to use additional extremely light components. Its viscosity is far more fluid or watery than typical concrete. Foamed concrete is frequently utilized as a substance that fills because it does not include big aggregates. Foamed concrete is a type of building material made from cement-based mortar **(Agboola et al., 2024)**. It is not organic and can be found in building blocks, reinforced or un-reinforced panels, and other functional building elements. Unlike normal concrete, it does not contain a coarse aggregate phase, making it relatively homogeneous. A novel type of lightweight concrete known as foamed concrete has many desirable properties, including minimum dimensional change, flowability, self-compaction and self-leveling nature, and ultra-low density. It is also possible to design the material to have exceptional load-bearing capacity, outstanding thermal insulating qualities, and controlled strength **(Abu-Jdayil et al., 2019; Mei et al., 2023)**.

Foamed concrete is a light-weight substance made of cementitious mortar encircling disconnected bubbles (more than 50% by volume). It is created by either chemical or physical processes that involve the introduction of air into the mortar mixture (un-foamed) or the formation of gas within it **(Tikalsky et al., 2004)**. A foamed concrete is a lightweight concrete made of cement or lime mortar that has an included volume of void in the mortar mass created by the application of a suitable foam agent. The properties of foamed concrete are determined by the even distribution of air bubbles all through the mass of concrete; bubbles of air in the newly mixed concrete must create a strong and stable wall and must not collapse during combining, transport, pumping, and placing; the size of the bubble in foamed concrete varies from 0.1 to 1 mm **(Neville, 2010)**. The composition and method of production determine the properties of the foamed concrete, which are affected by the type of binder utilized, foam formation techniques, and curing methods recommended. Broadly speaking foamed concrete falls into the group of cellular concrete or void concrete. The inclusion of bubbles instead of the conventional aggregate reduces the self-weight of concrete, which in turn decreases the overall structure's dead loads. This contributes to reducing cross-sections and loads of structures, and then more economic designs and functionality can be achieved. The density of foam concrete can be found through the volume of the material and that of the foam in the mortar and these densities range from 300 and 1600 kg/m^3 **(Usman et al., 2024)**. The production of foamed concrete eliminates coarse aggregate completely, and even fine aggregates can be replaced entirely or in part with renewable materials such as fly-ash metakaolin, laterite, a rice husk ash, the quarry dust, volcanic ash, silica fume, etc. The resulting concrete has a lot of potential for structural uses. It is thought that foamed concrete will be used as insulation due to its excellent properties, which include movement, thermal characteristics, acoustic properties, and strength; for densities ranging from 500 kg/m^3 to 1400 kg/m^3, the strength value is typically 1N/mm^2 to 9N/mm^2 **(Raj et al., 2019)**.

The main goal of building design is that the building's components must be able to withstand the loads exerted on them. A basic strength test can reveal various other significant qualities that are more challenging to quantify directly, which makes strength crucial as well **(Peter and John, 2010; Agboola et al., 2020b)**. Strength is the most significant single quality of concrete. There are a number of connections that can be used to predict the strength of concrete; these relationships are typically based on Abram's Law, which just considers the ratio of cement to water. Nonetheless, a superior substitute for foamed concrete is Feret's expression, which took into account a great deal of air voids **(Tam et al., 1987)**.

Researchers have created relationships to estimate the strength of foamed concrete. However, using strength-predicting mathematical models, researchers have compared the strength-porosity and gel-space ratio for foamed concrete integrating fly ash **(Nambiar and Ramamurthy, 2008)**. They discovered a strong correlation between the measured strength and expressions obtained from the strength-porosity model. The usage of recycled materials and compressive strength of foamed concrete have garnered attention recently, despite the inconsistent studies in this area. It has been demonstrated in recent studies **(Agboola et al., 2022a; Agboola et al., 2022b; Nagrale et al., 2012; Bui, 2001)** that rice husk ash can replace cement in concrete manufacture by up to 30%. On the other hand, the most basic test for compressive strength involves the use of a concrete cube and is the industry standard in many nations. The cube needs to be big enough, like 100 mm or 150 mm, and it is typically cast in lubricated metal or plastic molds that have been precisely machined to guarantee that the opposing edges are parallel and smooth. The concrete cube is taken out of the mold and allowed to cure using any appropriate curing technique at a consistent temperature for the duration of the testing time. The concrete that is produced using the aforementioned procedures is considered robust and long-lasting.

The goal of the current study is to validate the compressive strength at 28 days of curing using parameters like the properties of the constituent material, the fresh density, and the compression strength of samples of concrete. The foamed concrete produced with ash from rice husks as a partial cement replacement will be strengthened using a strength and porosity relation. With advancements in concrete technology recently, researchers have utilized different techniques to evaluate and predict the properties of foamed concrete. A simple prediction model is put forward when no experimental data are available.

Predicted model for compressive strength of foamed concrete considering pore size distribution, the effects of density, water-cement ratio, and foaming agent type on porosity were studied; it was also found that smaller porosity, more concentrated and uniform pore size distribution were more beneficial for strength **(Bian et al., 2023)**. **(Jiang**

et al., 2024) investigated the size effect on the compressive strength of foamed concrete at the mesoscale level combining X-ray computed tomography (X-CT) and a discrete lattice model. The model was verified experimentally at a wet density of 700 kg/m^3 and then used to predict the strengths of specimens with wet densities of 600 and 800 kg/m^3. The results show that the air void structure significantly influences the observed size effect on the compressive strength in the investigated size range. **(Zhao et al., 2018)** predicted a model for the compressive strength of foamed concrete for three types of high-porosity cast-in-situ parameters (cement mix, cement-fly ash mix, and cement-sand mix) with dry densities of less than 700 kg/m^3. The model is an extension of Balshin's model and takes into account the hydration ratio of the raw materials, in which the water/cement ratio was constant for the entire construction period for a certain casting density. The results show that the measured porosity is slightly lower than the theoretical porosity due to a few inaccessible pores. **(Nambiar and Ramamurthy, 2008)** proposed prediction relations for the compressive strength of foam concrete by extending two of the well-known relations available for cement paste, mortar and normal concrete, using Balshin's strength-porosity model and Power's gel-space ratio equation. The theoretical equations were derived for porosity and gel-space ratio relating it to the density, proportion of ingredients in the mix and material characteristics like specific gravity. Foam concrete with fly ash showed lesser dependency on pore parameters than cement-sand mixes. As both the prediction relations developed in this study consider the effect of composition on the strength, it can serve as a simple tool for predicting the strength of foam concrete. Hence, the evaluation and prediction of both the density and compressive strength are essential and of great importance for the practical application of sustainable foamed concrete. Overall, the study is undertaken to strengthen existing literature by predicting a strength porosity model of foamed concrete produced with rice husk ash as cement replacement.

2. MATERIAL AND METHODS

2.1 Materials

The primary binder was Ordinary Portland Cement, which was produced in accordance with **(BS 12, 1996)**. The rice mill in the Mudawal market in Bauchi city provided the rice husk that was used to make rice husk ash. The rice husk ash was burned at a temperature of 700^{O}C for 5 hours. For this project, river sand from Bauchi's Yelwa River was utilized. According to **(BS 882, 1992)**, fine material passes through a 300-micron sieve size but is held on a 150-micron sieve aperture. Because coarser aggregate just sits in the mix and affects the stability of foam because of its roughness and gradation, finer aggregate is employed to prevent foam collapse in the concrete mix. For this experiment, a protein-based foamed agent and drinkable, portable water were used. This is important because organic contamination can lower the quality of the foam and the concrete that is produced when utilizing a protein-based foamed agent.

2.2 Method

Using the target plastic density of 1600 kg/m^3 (±50 kg/m^3) as the design criterion, a mixed proportion was determined. Mixing was done in a concrete mixer. Initially, cement, sand and water were made in a slurry form to which pre-formed foam in calculated quantity was added. The foam was generated in a separate foam generator and added to the slurry. After mixing for 2 minutes, the mix was immediately poured into molds to avoid the coalescence of bubbles. The concrete underwent membrane curing or sealed curing. Presently, there isn't a set procedure for implementing foamed concrete mix design. Trial mixes were created for this investigation in order to attain workability and density using the local resources that were accessible. **Table 1** presents the constituent quantity used in the production of foamed concrete.

Table 1. Constituent Quantity for Foamed Concrete Mix

Quantity of Constituent Materials for Foamed Concrete Mixes in kg/m³						
%RHA	Binder(kg/m³)		Fine aggregate (kg/m³)	Base Mix Water (kg/m³)	Foam Concentration	
	Cement	RHA			Mixing Water (kg/m³)	Foam (g/m³)
0%	500	0	850	250	12.78	227.2
5%	475	25	850	250	12.6	224
10%	450	50	850	250	12.42	220.8
15%	425	75	850	250	12.24	217.6
20%	400	100	850	250	12.02	213.6
25%	375	125	850	250	11.84	210.4
30%	350	150	850	250	11.7	208

2.3 Developing Strength Model

The expression relating the porosity and the compressive strength of foamed concrete with cement paste was developed by **(Hoff, 1972)**. He used a simple model in which foamed concrete is composed of air, evaporable water, non-evaporable water, and cement as shown in **Fig. 1**.

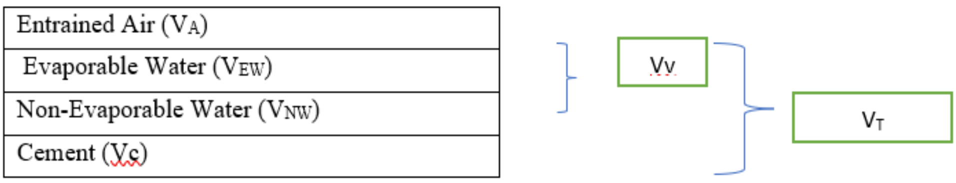

Figure 1. Foamed concrete composition developed by Hoff model.

The foamed concrete material composition used by the Hoff Model has been expanded in this research to include sand and binder (cement and rice husk ash). The modified model for strength development to be adopted for this research is presented in **Fig. 2**. Considering that foamed concrete is a high-porosity material, a relation involving strength and porosity is considered a suitable tool for predicting the strength of foamed concrete **(Nambiar and Ramamurthy, 2008)**.

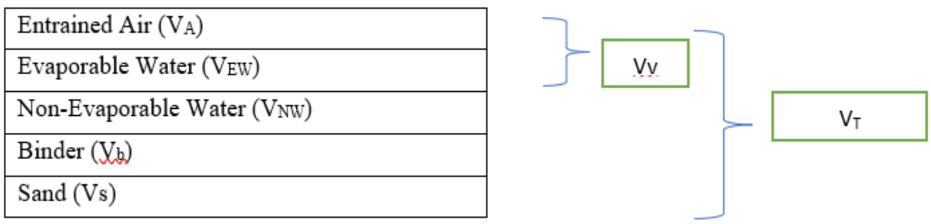

Figure 2. Modified form of foamed concrete composition.

where
$V_A =$ Volume of air entrained in foamed concrete by aeration process
$V_{EW} =$ Volume of evaporable water
$V_{NW} =$ Volume of nonevaporable water

$$V_{NW} = 0.20 P_B V_B \quad (1)$$

where:
$P_B =$ Specific gravity of cement and rice husk ash (binder)
$V_B =$ volume of cement and rice husk ash (binder)
The amount of binder used in the mixture of cement and rice husk ash. However, the amount of cement in the control mix is limited to the volume of foamed concrete.
$V_S =$ quantity of fine aggregate (sand)
The parameters above have been used in this study in the validation of the strength development model for foamed concrete.

The equation is thus expressed as:

$$fc = fo\,(1-p)^{n} \quad (2)$$

where:
$f_c =$ compressive strength at 28th day of curing
$f_o =$ intrinsic compressive strength at zero porosity
$p =$ porosity
$n =$ empirical constant which depends on the characteristics and properties of the material

Using a weight-volume relationship according to **(Hoff, 1972)**, foamed concrete theoretical porosity, p for foamed concrete, Vv which is the sum volume of all voids, and total volume V_T, can be expressed as:

$$p = \frac{Vv}{V_T} \quad (3)$$

$$p = \frac{V_A + V_{EW}}{V_B + Vw + Vs}$$

where:
$V_{EW} =$ volume of nonevaporable water
$V_B =$ volume of binder (cement + rice husk ash)
$V_W =$ volume of water i. e evaporable and nonevaporable water ($V_{EW} + V_{NW}$)
The volume of water, Vw, in this statement, is made up of both evaporable and non-evaporable water. Furthermore, defined in **Fig. 2** are V_B, which denotes the volume of the binder made of cement as well as rice husk ash, along with other characteristics.
Additionally, using the values shown in **Fig. 1**, the foamed concrete wet density (dc), related to W_T (the overall weight of the constituent materials) and V_T (the total volume of all materials), can be written as follows:

$$dc = \frac{W_T}{V_T} \quad (4)$$

$$dc = \frac{W_B+W_W+W_S}{V_B+V_{NW}+V_S+V_V} \tag{5}$$

where:
$W_B =$ weight of binder (cement and rice husk ash)
$W_W =$ weight of water
$W_S =$ weight of fine aggregate (sand)
$V_B =$ volume of binder (cement and rice husk ash)
$V_{NW} =$ volume of nonevaporable water
$V_S =$ volume of fine aggregate (sand)
$V_V =$ volume of all voids in the material components

Now if Kws is water to solid relative amount by weight (solid being cement, rice husk ash, and fine aggregate), then Kws becomes:

$$\text{Kws} = \frac{W_W}{W_B+W_S} \tag{6}$$

$$W_W = K_{WS}\,(W_B + W_S) \tag{7}$$

insert Eq. (7) into Eq. (5), it becomes:

$$\text{dc} = \frac{(W_B+K_{WS}(W_B+W_S)+W_S}{(V_B+V_{NW}+V_S+V_V)}$$
$$= \frac{(W_B + K_{WS}W_B + K_{WS}W_S + W_S)}{(V_B + V_{NW} + V_S + V_V)}$$
$$= \frac{(W_B + K_{WS}W_B + W_S + K_{WS}W_S)}{(V_B + V_{NW} + V_S + V_V)}$$
$$= \frac{(W_B\,(1 + K_{WS}) + W_S\,(1 + K_{WS})}{(V_B + V_{NW} + V_S + V_V)}$$
$$\text{dc} = \frac{(1+K_{WS})\,(W_B+W_S)}{(V_B + V_{NW} + V_S + V_V)} \tag{8}$$

Considering Eq. (4)

$$W_T = d_C V_T \tag{9}$$
$$V_T = V_B + V_{NW} + \text{Vs} + V_V \tag{10}$$

substitute for the values of dc and V_T in Eq. (9), it shows that:

$$W_T = \frac{(1+K_{WS})\,(W_B+W_S)}{(V_B+V_{NW}+\text{Vs}+\text{Vv})} \text{ x } (V_B + V_{NW} + \text{Vs} + V_V)$$
$$(W_T = (1 + \text{kws})\,(W_B + W_S) \tag{11}$$

Substituting for W_T and V_T in Eq. (9), we now have:

$(Dc = V_B + V_{NW} + \text{Vs} + \text{Vv}) = (1 + \text{kws})\,(W_B + W_S)$
$dc\text{Vb} + \text{dc}V_{NW} + \text{dcVs} + \text{dcVv}) = (1 + \text{kws})\,(W_B + W_S)$
$dcVv + dc(V_B + V_{NW} + \text{Vs} + \text{Vv}) = (1 + \text{kws})\,(W_B + W_S)$
substituting for the value of V_{NW} (from Eq. (1)) we have:

$$Vv = \frac{1}{\mathrm{dc}}(1 + \mathrm{kws})\ (W_B\ + W_S) - \mathrm{dc}\ (V_B + 0.2V_B P_B + \mathrm{Vs}\ ) \tag{12}$$

Now, recall the expression for the porosity p:

$p = \frac{\mathrm{Vv}}{V_T}$ (from Eq. (3))

$p = \frac{\mathrm{Vv}}{\frac{W_T}{dc}}$ (replacing V_T with $\frac{W_T}{\mathrm{dc}}$ in Eq. (4))

By combining Eq. (9) for W_T, and Eq. (12) for Vv, the expression for porosity p becomes:

$$p = \frac{\frac{1}{dc}(1+\mathrm{kws})(W_B + Ws) - dc\ (V_B + 0.20V_B P_B + Vs)}{\frac{\{(1+Kws)(W_B+Ws)\}}{dc}} \tag{13}$$

By Simplifying we have:

$$p\ = 1 - \frac{dc(V_B\ + 0.20V_B P_B\ + Vs)}{(1+\mathrm{kws})(W_B + \mathrm{Ws})} \tag{14}$$

The sand-to-binder ratio weight is represented by k_{SBW}, thus:

$$k_{SBW}\ = \frac{(W_S)}{(W_B)} \tag{15}$$

Then

$$Ws =\ k_{SBW}\ W_B \tag{16}$$

Also, the volume of sand to binder ratio as K_{SBV}, gives:

$$k_{SBV} = \frac{(V_S)}{(V_B)} \tag{17}$$

then

$$Vs =\ k_{SBV}\ V_B \tag{18}$$

Substituting Eq. (16) and (18) for Ws and Vs in Eq. (13) then,

$$p = 1 - \frac{dc(V_B\ + 0.20V_B P_B\ + K_{SBV} V_B)}{(1+\mathrm{Kws})(W_B\ + K_{SBW}\ + W_B)}$$

$$= 1 - \frac{dcV_B(1+0.20P_B+K_{SBV})}{(1+\mathrm{Kws})(1+K_{SBW})W_B}$$

$$= 1 - \frac{dcV_B(1 + 0.20P_B\ + K_{SBV})}{(1 + \mathrm{Kws})(1 +\ K_{SBW})\rho b \Upsilon w V_B}$$

$$p = 1 - \frac{dc(1+0.20P_B+K_{SBV})}{(1+\mathrm{Kws})(1+K_{SBW})\rho b \Upsilon w} \tag{19}$$

where Yw is the unit weight of water.
Now substituting Eq.(19) into Eq. (2) as:

$fc = fo\ (1 - p)^n$ for strength and porosity relation, the equation becomes:

$$fc = fo\left(\frac{dc(1+0.20P_B+K_{SBV})}{(1+\text{Kws})(1+K_{SBV})\rho b \Upsilon w}\right)^n \quad (20)$$

where:
$f_C =$ compressive strength at 28 days of curing
$f_O =$ compressive strength at no pores
$d_C =$ foamed concrete wet density
$P_B =$ binder's specific gravity
$K_{SBV} =$ volume of sand to binder ratio
$K_{WS} =$ weight to solid ratio
$k_{SBW} =$ weight − based proportion of sand to binder

The formula is dependent on the physical properties of the component materials, which can be measured in a laboratory as a method of quality assurance. By applying the successive approximation principle and the Bisection Technique of numerical analysis **(Murthy, 2007; Scheid, 1989)**, the principles of the model assumptions f_0 and n were determined to be 97.26 N/mm^2 and 3.60 respectively (principle underlying the process method is contained in Appendix III). Using Eq. (20) and values of model constants found through principle of approximation, the equation becomes:

$$\text{fc} = 97.26\left(\frac{dc(1+0.20\rho b+K_{SBV})}{(1+\text{Kws})(1+K_{SBW})\rho b \Upsilon w}\right)^{3.60} \quad (21)$$

where:
$d_C =$ the fresh weight of the foamed concrete
$f_C =$ compressive strength at 28 days
$PB =$ the binder's specific gravity
$K_{SBV} =$ the volume ratio of sand to binder
$K_{WS} =$ the weight to solid ratio
$K_{SBW} =$ the weight − based ratio of sand to binder

In the laboratory, it is simple to measure the wet density, the binder's specific gravity, the volumetric and weight ratios of sand to binder, and the weight ratio of water to solid.

3. DISCUSSION AND VALIDATION

The values of the compressive strengths produced from applying Eq. (20), taking into account the physical properties in Appendices, are compared with the strength obtained from the experimental test in order to validate the derived strength-predicting mathematical model through the cube tests for every degree of rice husk ash replacement in cement. The experimental and model strength data are presented in **Table 2**.
All cement levels of replacement using rice husk ash, as shown in **Table 2**, are sufficiently equivalent to the model values derived from Eq. (21). The results of this study show that, for all cement replacement levels, the percentage discrepancy between the actual strength values and the generated model values ranges from 0% (for the control) to – 7.03% (for a 15% cement substitute).

Table 2. Experimental and Model Strength Comparison

% Replacement	Experimental (N/mm²)	Model (N/mm²)	% Difference
0%	15.22	15.22	0
5%	15.22	15.01	-1.42
10%	15.22	14.41	-5.61
15%	14.84	13.87	-7.03
20%	12.87	12.79	-0.6
25%	11.51	12.12	5.01
30%	10.84	11.46	5.42
Average	13.67	13.55	-0.6

According to **(Rao, 2011)**, laboratory-produced aerated concrete is deemed acceptable when the average difference is less than 15%. The maximum difference, 7.03%, occurred at the 15% replacement threshold. The overall average difference is -0.60%. From a statistical perspective, the mean density is 13.67N/mm², and the normal deviation is 0.60. The distribution of data around the median observed value was shown by the lower standard deviation value. Additionally, the test for statistical significance values at significance levels of 1%, 5%, and 10% indicated that the difference is not significant because the confidence values do not fall outside of the critical regions. This means that, at the confidence levels of 1%, 5%, and 10%, there is no reason to reject the model's outcome. To put it briefly, the strength-predicting theory in Eq. (21) is true as long as the percentage of cement replacement in foamed concrete made with rice husk ash and even control concrete made without any additives or admixtures is less than 30%.
Fig. 3 displays the strength curves for the model and the experiment. For the controlled concrete with foam (0% replacement), it can be seen that the experimental and model compressive strengths are the same. However, from 5% to 20% replacement, the experimental strength exceeds the anticipated strength, and from 25% replacement level and up, the experimental strengths show lower values than the predicted strengths.

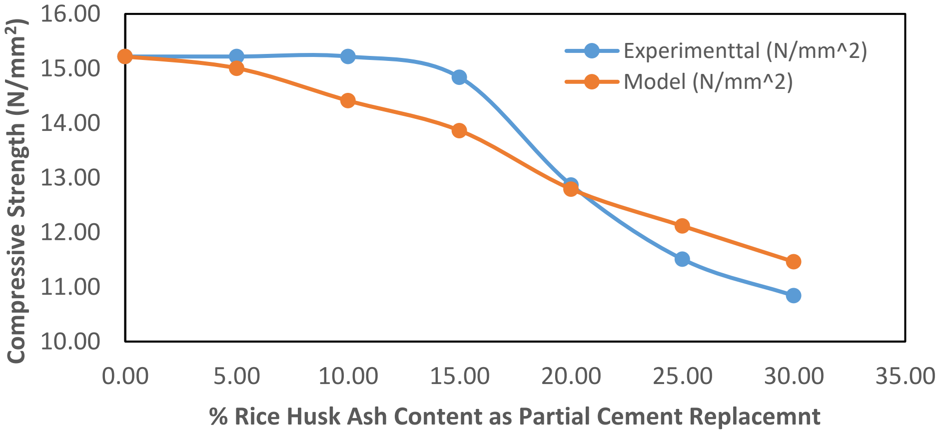

Figure 3. Variation of experimental and model strengths.

An illustration of the correlation between the values of the foamed concrete experimental strength and the model strength is provided by the scatter plot seen in **Fig.4**.

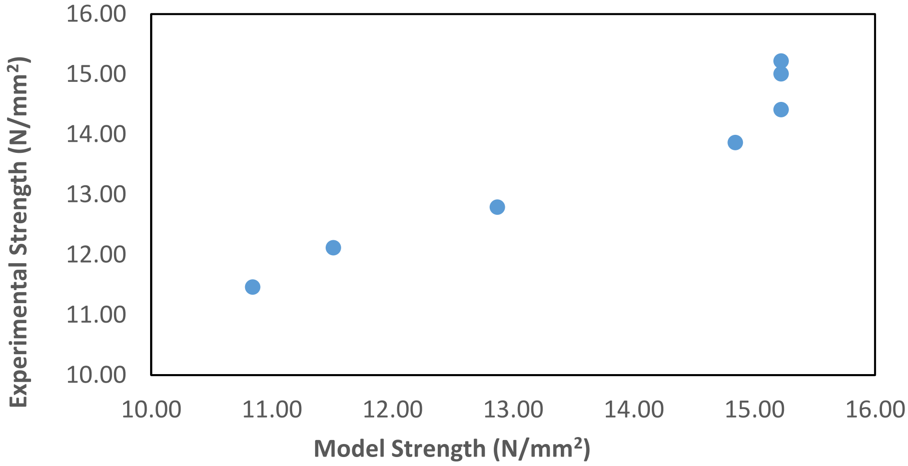

Figure 4. Experimental and model strength relationship

A 0.937 coefficient of correlation shows a positive and strong linear relationship between experimental strength values and the predicted values. The link between experimental and model strength can be represented as follows in a linear regression equation using the statistical line of best fit:

fcue= A* fcum + B (22)

where fcue= Experimental compressive strength.
fcum= Compressive strength of the model

The slope and intersections of the plot of the measured experimental compressive strength against the model compressive strength are represented, respectively, by A and B = the coefficients of regression.
Eq. (22) is then obtained by using regression analysis to get these coefficients:

fcue= 3.46 fcum - 0.74 (23)

4. CONCLUSIONS

The study was able to develop a mathematical model for predicting the 28-day compressive strength of foamed concrete with and without rice husk ash and validated at 28 days.

1. For a period of 28 days, the created compressive strength model was validated for foamed concrete made with 0% rice husk ash and foamed concrete made with 5% to 30% rice husk ash at 5% intervals. The created model indicates that characteristics and mix quality may be identified and managed directly from the site, predicting the compression strength of the foamed concrete at 28 days of age from the fundamental component materials for generated foamed concrete and the newly created foamed concrete.
2. This study indicates that by regulating the mixing process, the density, stability, and characteristics of the materials employed in the production of foamed concrete can be used to forecast strength. A precise understanding of the material's qualities, the ratio of

sand to binder, the proportion of mix, the quantity of foamed agent needed, and the necessary density will help foamed concrete build a stable mix and strength.

3. The rheological characteristics of the bubbled concrete mix and how it behaves during the hardened stage are directly influenced by the proportion of pozzolanic addition and the quantity of water needed for a mix. Furthermore, understanding the fundamental ingredients required to produce foamed concrete will be crucial for precise strength behavioral property prediction and practical application. The compressive strength increases with the increase in the ratio of dry density to solid density.
4. Based on the results that the compressive strength changes with the porosity and the curing time, a prediction model taking into account the mix constituent, curing time, and porosity is proposed. A simple prediction model is put forward when no experimental data are available.

Credit Authorship Contribution Statement

Agboola Shamsudeen Abdulazeez: Writing – review & editing, Writing – original draft. Shabi Moshood Olawale: Validation. Musa Abdulhakeem Kolawole, Aliyu Zakari: Software. Ridwan Abdulsalam Abiodun, Bukar Aliyu: Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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نموذج تنبؤي للمتانة للخرسانة الرغوية المنتجة باستخدام رماد قشر الأرز كبديل جزئي للإسمنت

أغبولا شمش الدين عبدالعزيز[1]،*، شابي مشود أولاوالي[1]، عليو زكاري[2]، موسى عبد الحكيم كولاولي[1]، رضوان عبد السلام أبيودون[1]، بوكار عليو[1]

[1]قسم البناء وحساب الكميات، كلية العلوم البيئية، جامعة أبوجا، العاصمة الفيدرالية، أبوجا، نيجيريا

[2]قسم العمارة والتصميم الصناعي، كلية العلوم البيئية، جامعة أبوجا، العاصمة الفيدرالية، أبوجا، نيجيريا

الخلاصة

الخرسانة الرغوية هي نوع من الخرسانة خفيفة الوزن يمكن تصميمها لتلبية معايير محددة من القوة أو الكثافة. يضمن التصميم الفعّال للخرسانة الرغوية تحقيق الخصائص المطلوبة من المتانة والقوة. تهدف هذه الدراسة إلى التنبؤ بمقاومة الضغط للخرسانة الرغوية المنتجة باستخدام رماد قشر الأرز كبديل جزئي للإسمنت بنسبة تتراوح بين 5–30%، وذلك باستخدام نموذج التنبؤ بالقوة–المسامية مع كثافة قدرها 1600 كجم/م^3. لإنشاء هذا النموذج، تم استخدام العلاقة بين خصائص القوة والمسامية. كما تم إيجاد الثابت الأساسي باستخدام طريقة التحليل العددي (طريقة التنصيف الثنائي). تتناول هذه الدراسة خصائص المواد المكونة الأساسية والكثافة التي تؤثر على الحالة الصلبة، وذلك لاستكشاف خصائص الخرسانة الرغوية. وبناءً على صحة النتائج، يمكن استنتاج أن النموذج مناسب للعينة التي تم اختبارها في المختبر من الخرسانة الرغوية المصنوعة باستخدام رماد قشر الأرز كبديل جزئي للإسمنت. يتطابق نموذج القوة–المسامية بشكل جيد مع القوة المقاسة مخبرياً لأنه يعتمد على تركيب المكونات. ومن الواضح أنه يمكن إنتاج نموذج تنبؤي للقوة من خلال اختيار معايير مثل الكثافة، وخصائص المواد، والنسب لتتناسب مع أغراض واستخدامات مختلفة.

الكلمات المفتاحية :مقاومة الضغط، كثافة التصميم، الخرسانة الرغوية، القوة–المسامية، رماد قشر الأرز.

Appendix A
Bisection Method of Numerical Analysis
The intermediate value theorem serves as the foundation for the bisection approach employed in this study, which finds the non-linear form of an equation's root:
If f(x) = 0, then (1)
Since the square root of Eq. (1) exists within the open range of (a,c), we can apply the rule f(a)*f(c) < 0 (2).
The procedure begins with dividing the interval (a,c) into two halves, denoted as (a,b) and (b,c), where: b= (a+c)/2 (3)
In the event that "b" is not the answer to Eq. (1) which is used to test both divisions once more in order to determine which one will meet Eq. (2). The same process is continuously applied to split the interval comprising the root until a rough root of Eq. (1) is achieved, subject to a certain error margin that is deemed acceptable. Nevertheless, through a series of rounds, a continuous interpolation technique is used to estimate the square root of Eq. (1) within the allowable error range. The neighborhood N of Eq. 1's root, or the space associated with the root, is used to estimate the root. When (N)<E, the iterative process comes to an end (where E is a pre-specified error size). The following is a description of an algorithm frequently used in the Division method.
Technique for Bisection
After determining that the primary cause x of f(x) exists within the interval I = (a, b), the following procedures will be followed in order to use the technique for the bisection process to discover the roots of Eq. f(x) = 0:
1) Xl and Xu are said to be in the interval T = (a, b) if f(x1) f(xu) < 0.
2) Determine the midway point between x1 and xu, or xm = (x1+xu)/2, to estimate the root, Xm, of the Eq. f (x) = 0.
3) Currently verify the following: The root is located between x and xm if f(x1) f(xm) < 0. If f(x1)f (xm) > 0, then xm and xu are where the root is located. The root is xm if f (x1) f (xm) = 0. When the algorithm ceases, move on to (d). Find the updated root estimate.
4) Determine the total relative error by finding the new estimation of the root, xm= (x1+xu)/2, and using the formula /ɗ_a/= (x^new- x^old)/x^new x 100. where xnew is the estimated error based on the current iteration. xold = expected error from the preceding cycle
5) Examine the difference between the predetermined relative error tolerance əs and the measured relative effectiveness error /{\a/. Proceed to step 3 or halt the algorithm if /ɗa/ >əs.

Since the procedure of doubling the interval causes the process to lag, employing this strategy in iteration is significant since it will never converge on the root. Additionally, as iterations are processed constantly, the interval is reduced, allowing for minimum inaccuracy in the Eq.'s solution.

Appendix B:
Table B1. Scenery Time and Physical property of Rice Husk Ash (RHA)/Cement mortar

%RHA*	SG	W/C Ratio for SC	Setting Times	
			Initial	Final
0	3.10	0.50	61	114
5	3.05	0.50	68	128
10	3.04	0.50	72	149
15	3.02	0.50	89	184
20	3.02	0.50	101	211
25	3.01	0.50	121	232
30	3	0.50	148	258
35	2.94	0.50	151	322
40	2.91	0.50	156	368
45	2.83	0.50	171	384
50	2.79	0.50	236	389

Table B2. Foamed Concrete's Plastic Density at 1600 kg/m^3

%RHA*	Plastic Density
0	1641
5	1635
10	1635
15	1627
20	1614
25	1604
30	1589

Table B3. Compressive Strength Development Model Development

%RHA*	k_{SBW}	k_{SBV}	kws(T)	p_B	dc	A	B	P= A/B	Fc (N/mm^2)
0	1.7	2.02	0.194652	3.10	1641	5973.2400	9999.236	0.5974	15.22
5	1.7	1.97	0.194519	3.05	1635	5853.3000	9836.860	0.5950	15.22
10	1.7	1.92	0.194385	3.04	1635	5768.2800	9803.514	0.5884	15.22
15	1.7	1.88	0.194252	3.02	1627	5668.4680	9737.930	0.5821	14.84
20	1.7	1.83	0.194089	3.02	1614	5542.4760	9736.601	0.5692	12.87
25	1.7	1.79	0.193956	3.01	1604	5440.7680	9703.277	0.5607	11.51
30	1.7	1.76	0.193852	3	1589	5339.0400	9670.200	0.5521	10.84