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Prediction of Optimal Dosage of Rice Husk Ash in Blended Cement for Production of Hollow Sandcrete Blocks Using Response Surface Methodology

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ABSTRACT

Rice Husk Ash (RHA) is a supplementary cementing material which is obtained through the combustion of rice husk. It is capable of replacing Portland Limestone Cement (PLC) up to 30%, depending on its degree of pozzolanic activity but it is deficient in early age strength development. Based on this, this study predicted the optimum replacement content of PLC with RHA for production of Hollow Sandcrete Blocks (HSB) using Response Surface Methodology (RSM) at 90 days curing age of the HSB. HSB of sizes 450 x 225 x 225 mm, and 450 x 150 x 225 mm were produced using mix ratio 1:6 and 1:8, respectively. A total number of two hundred and eighty-eight blocks were produced and the properties (Density, Compressive Strength (CS), Water Absorption Capacity and Abrasion) of the HSB were subjected to Analysis of Variance (ANOVA). The ANOVA of the models of the chosen variables (RHA fineness and contents) indicate a significant level at $p < 0.0001$ (which is lesser than 0.05) for all the responses (Density, CS, WAC and Abrasion). For sustainable use of RHA as substitute of PLC in HSB, 34% RHA content was predicted by the response surface methodology model.

Keywords: Rice Husk Ash, Blended Cement, Hollow Sandcrete Blocks, Optimization

Hollow Sandcrete Blocks (HSB) are the common types of sandcrete blocks. They are usually 450 × 225 × 225 mm for load bearing walls and 450 ×150 × 225 mm for non-load bearing walls (NIS 87: 2007; Anosike and Oyebande, 2012; Odeyemi et al., 2019). The quality of sandcrete blocks is influenced by so many factors such as the quality of constituent materials, the process adopted in manufacture, duration of curing, forms and sizes of blocks (Adewuyi et al., 2013; Quadri and Ijesoh, 2017). The composition of a sandcrete block is PLC, fine aggregate (sand) moistened with water and allowed to dry naturally (Erakpoweri and Onah, 2022; Wilson et al., 2024). Cement is the most expensive component of sandcrete block. Cement is an essential construction material that is used principally as binder in cement-based construction. Increase in price of cement has necessitated the need to find replacement for it either partially or fully (Raheem et al., 2018). The quest for replacement of cement assist greatly to drive down the cost of construction as well as to cause a reduction in greenhouse gases generated during its production (Carvalho, et al., 2019; Ikeagwuani et al., 2020; Devarangadi and Uma, 2020; Chen et al., 2021; Edalat-Behbahani et al., 2021; Wang et al., 2022; Gu et al., 2023; Zeng et al., 2023). In view of this, Rice Husk Ash (RHA) which is an evident pozzolanic material was used as partial replacement for PLC in in this study, with the aim of predicting the optimum replacement of PLC with RHA for production of HSB (using response surface methodology).

RHA is an agro based waste material that is generated through combustion of rice husk, either by open burning or in a controlled temperature (Ikhlaq et al., 2018; Zhang et al., 2020). When properly burnt, cellulose and lignin are

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removed, and it has high silica content (Ajayi et al., 2021; Malek et al., 2022). It is readily available for application in various fields; as an admixture in mortar and concrete (Amran et al., 2021); as an adsorbent for organic molecules and metals from aqueous media (Sharma and Ghose, 2016); as well as in the field of effluent treatment as either an adsorbent or as a substrate (Xie et al., 2018). The use of RHA in Portland Limestone Cement (PLC) as a Supplementary Cementitious Materials (SCMs) has increased recently (Singh, 2023; Alieu et al., 2024). Supplementary use of RHA as blended PLC or concrete is not a new technique but started around the year 1970. Since then many research and development in various parts of the world, have shown that RHA can be used as a partial replacement for PLC in mortar and concrete because of its very high silica content, where rice plant is one of the plants that absorbs silica from the soil and assimilates it into its structure during the growth. It stands out as an eco-friendly, sustainable and durable SCMs for mortar and concrete production (Khassaf et al., 2014; Guruvu et al., 2016). Numerous researches (Obilade 2014; Raheem and Kareem, 2017a; Raheem and Kareem, 2017b; Ige et al., 2018; Anifowose et al., 2018; Abubakar, 2018; Khan et al., 2021; Oriola et al., 2021; Das et al., 2022; Raheem and Anifowose, 2023; Anifowose and Raheem, 2024) have been carried out on the use of RHA in mortar or concrete as SCMs. Hence, its application in Hollow Sandcrete Blocks (HSB) is essential towards sustainable housing and construction.

2. MATERIALS AND METHODS

2.1 *Materials*

The RHA used for production of HSB was obtained from Hillcrest Agro- Allied Industries Limited, Amberi, Kwara State, Nigeria (Long. 8°14′45.1392″ and Lat. 4°32′29.6916″ E). PLC of grade 42.5N which conforms to NIS 444–1 (2014) was used with portable drinking water. And Fine Aggregate (FA) that passes through maximum British Sieve of 4.75 mm in conformity to BS EN 12620 (2002+A1:2008) was used.

2.2 *Methods*

RHA fineness (75, 150 and 300 μm), and PLC to FA mix proportion of 1:6 and 1:8 was adopted (in accordance to NIS 978, 2017) for production of 450 x 225 x 225 mm HSB and 450 x 150 x 225 mm HSB, respectively. The PLC was substituted with RHA at 10, 20, 30, 40 and 50% by weight. The blocks were cured by sprinkling for 90 days. A total number of two hundred and eighty-eight blocks (144 for 450 x 225 x 225 mm and 144 for 450 x 150 x 225 mm) were produced. Density, compressive strength, water absorption capacity and abrasion of the blocks were determined. Hence, the average results of the total number of blocks lead to 96 outputs.

The results of the HSB properties (density, compressive strength, water absorption capacity and abrasion) were subjected to Analysis of Variance (ANOVA). Import data set, under Response Surface Methodology (RSM) in Design Expert version 13.0 (statistical software from Stat-Ease Incorporated) was used in determining the ANOVA of the density, Compressive Strength (CS), Water Absorption Capacity (WAC) and Abrasion (AB) of the HSB. An optimization process was conducted on the 150 and 225 mm HSB sizes. The goal was to maximize the RHA content and CS, towards achieving sustainable HSB. Hence, the optimum response value of the models was compared with NIS standard. In determining the maximum response value of the 150 and 225 mm Hollow Sandcrete Block (HSB), two factors were chosen as follows: A, RHA fineness (75 - 300 μm) and B, RHA content (0 - 50%) at two levels with four responses: Density, CS, WAC and AB.

3. RESULTS AND DISCUSSION

3.1 *Process Optimization*

Optimization of the response values were evaluated on the HSB at 90 days, due to the fact that RHA have deficiency in early age strength development upon having the quality to improve properties of cement composite (Bie et al., 2015; Jamilu et al., 2023). The WAC and AB were analysed at 28 days curing age (maintaining standard test age).

3.2 *Effect of Process Optimization on HSB*

The optimal plots for the response variables are presented in Figures 1 and 2, for 150 mm HSB and 225 mm HSB, respectively. The ramp profiles illustrate the desirability of hardened concrete as a function of the factors.

A desirability of 0.723147 and 0.731797, for 150 mm and 225 mm HSB (Figures 3 and 4) with a maximum response value of Density (2216.29 and 2069.17 kg/m^3); CS (3.50403 and 4.39174 N/mm^2); WAC (4.78958 and 5.05218%); and AB (0.306039 and 0.229567%) is obtained at A = 75 and 75; and B = 34.6283 and 33.5044%, respectively. These optimal values of density and WAC are within the recommended values of 1500 kg/m^3 and 12%, respectively by NIS 87 (2007). Hence, the maximum response of the CS is higher than the recommended CS of 2.5 and 3.45 N/mm^2 for 150 and 225 mm HSB, respectively. This is an insight on the production of sustainable HSB through waste minimization without affecting HSB strength.

Analysis of Variance (ANOVA) method was employed at $p < 0.05$ in order to estimate the significance and accuracy level of the model which resulted in Equations (1), (2), (3), (4), (5), (6), (7) and (8) for Density-150 mm (Quadratic Model), CS-150 mm (Quadratic Model), WAC-150 mm (2FI Model), AB-150 mm (Quadratic Model), Density-225 mm (Quadratic Model), CS-225 mm (Quadratic Model), WAC-225 mm

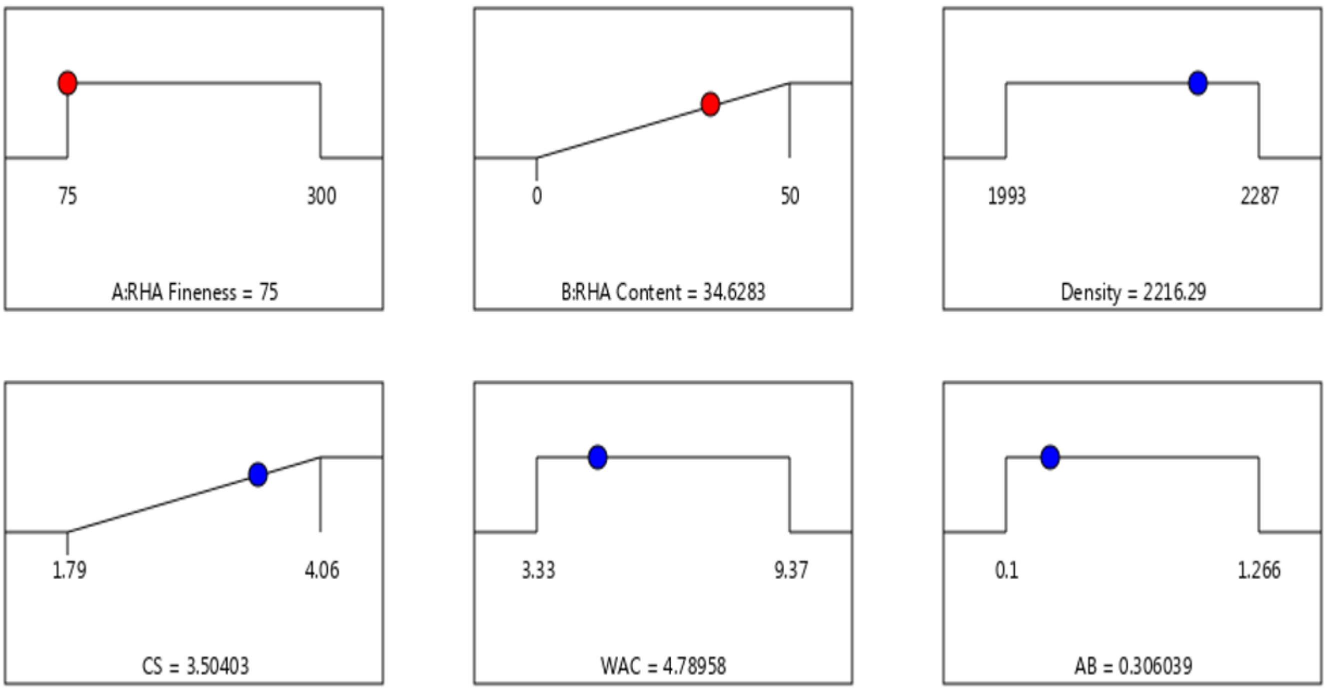

Figure 1: Optimal response of 150 mm hollow sandcrete block

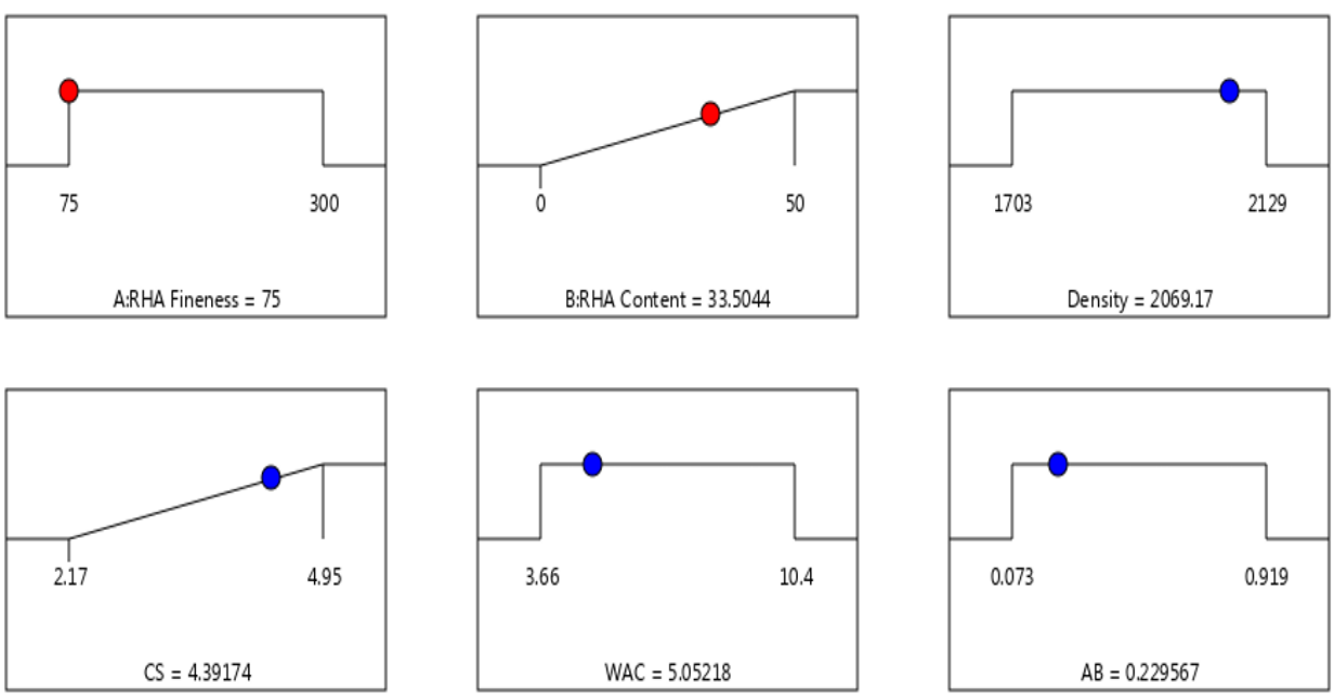

Figure 2: Optimal response of 225 mm hollow sandcrete block

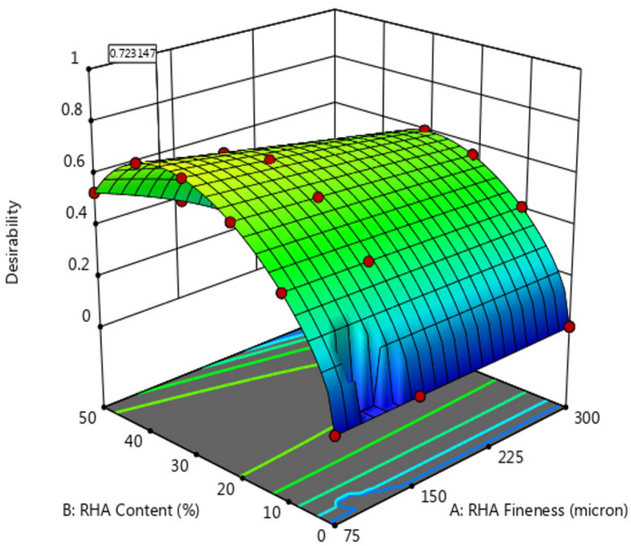

Figure 3: Desirability of 150 mm HSB

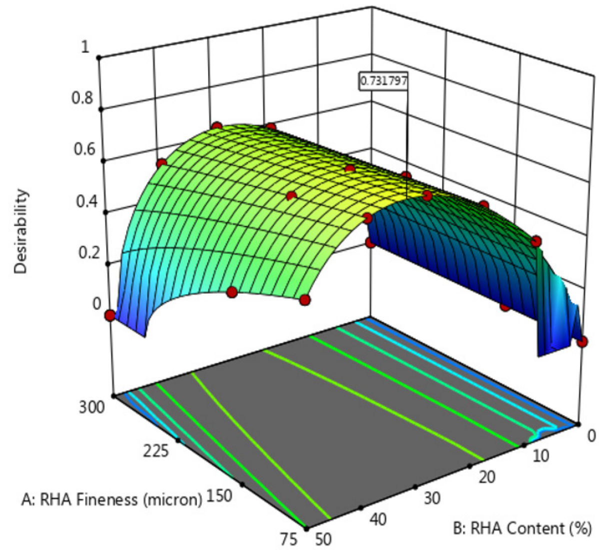

Figure 4: Desirability of 225 mm HSB

$$Density::150\,mm = 2208.30 - 42.67\text{A} - 68.66\text{B} - 18.59AB + 1.19A^2 - 111.76B^2 \quad (1)$$

$$CS:150\,mm = 3.64 - 0.2317\text{A} - 0.8162\text{B} - 0.2141AB - 0.0087A^2 - 0.8248B^2 \quad (2)$$

$$WAC:150\,mm = 5.56 + 1.11\text{A} + 1.85\text{B} + 0.9632AB \quad (3)$$

$$AB::150\,mm = 0.3439 + 0.2000\text{A} + 0.3841\text{B} + 0.1481AB + 0.0486A^2 + 0.1529B^2 \quad (4)$$

$$Density::225\,mm = 2034.94 - 54.67\text{A} - 118.23\text{B} - 39.61AB + 24.25A^2 - 155.06B^2 \quad (5)$$

$$CS:225\,mm = 4.61 - 0.2258\text{A} - 1.10\text{B} - 0.1877AB - 0.0100A^2 - 1.09B^2 \quad (6)$$

$$WAC:225\,mm = 5.72 + 1.078\text{A} + 2.24\text{B} + 0.8467AB - 0.1919A^2 + 1.01B^2 \quad (7)$$

$$AB:225\,mm = 0.2652 + 0.1252\text{A} + 0.2912\text{B} + 0.0904AB + 0.0057A^2 + 0.1332B^2 \quad (8)$$

(Quadratic Model), AB-225 mm (Quadratic Model), respectively.

The ANOVA of the models are presented in Tables 1 and 2. The models' F values of 27.20, 37.32, 100.13, 66.47, 103.34, 68.43, 34.08, and 65.34, for Density-150 mm, CS-150 mm, WAC-150 mm, AB-150 mm, Density-225 mm, CS-225 mm, WAC-225 mm, and AB-225 mm, respectively, for the variables (A and B), were all significant at $p < 0.05$ (5%) as presented in Tables 1 and 2 (Odeyemi et al., 2020; Design Expert 13.0, 2021; Adedokun and Anifowose, 2022; Liu and Yang, 2022; Adetoro et al., 2023).

The coefficient of determination (R^2) values of the 150 and 225 mm HSB ranged from 0.9189 – 0.9652, and 0.9342 – 0.9773, respectively (Tables 1 and 2). The R^2 value explains how well the model fits the given data and it is expressed in values between 0 - 1 (0 - 100%) (Sojobi et al., 2021; Bassi et al., 2023; Sathiparan 2024). For the developed models in this research work, the R^2 values were 91.89 – 96.52%, and 93.42 – 97.73%, for the 150 mm and 225 mm HSB, respectively. These high values of R^2 (close to 1 or 100%) are good indication of the responses of the developed models, proving its robustness and reliability (Adamu et al., 2021; Jamilu et al., 2023; Alieu et al., 2024; Alfanda, 2025).

The Predicted R^2 (Tables 1 and 2) of 0.7735; 0.8595; 0.9278; 0.9051; 0.9481; 0.9281; 0.8706; and 0.9022, for Density-150 mm; CS-150 mm; WAC-150 mm; AB-150 mm; Density-225 mm; CS-225 mm; WAC-225 mm; and AB-225 mm, respectively are in reasonable agreement with the Adjusted R^2 of 0.8851; 0.9144; 0.9459; 0.9506; 0.9678; 0.9520; 0.9068; and 0.9498, having difference of < 0.2 (Behera et al., 2018; Montgomery, 2017; Adamu et al., 2022; Ikponmwosa et al., 2023; Adedokun et al., 2024; Anifowose et al., 2024a). The "Adequate Precision" ratio of 18.7411 (Density-150 mm), 19.9210 (CS-150 mm), 32.0024 (WAC-150 mm), 27.2597 (AB-150 mm), 36.0134 (Density-225 mm), 25.5206 (CS-225 mm), 19.6390 (WAC-225 mm), and 26.7775 (AB-225 mm), are higher than 4, which are desirable for the models' and indicates an adequate signal (Ogunleye et al., 2015; Ogunleye et al., 2018; Busari et al., 2019; Anifowose et al., 2021; Adedokun et al., 2021; Abdulkarim et al., 2023; Jamilu et al., 2023; Design

Table 1: ANOVA of 150 mm HSB

Responses	Source	Sum of square	df	Mean square	F ratio	p value
Density	Model	97608.56	5	19521.71	27.20	< 0.0001*
	Residual	8613.05	12	717.75		
	Cor total	1.062E+05	17			
$R^2 = 0.9189$; Adj $R^2 = 0.8851$; Pred $R^2 = 0.7735$; Adeq precision = 18.7411						
CS	Model	8.16	5	1.63	37.32	< 0.0001*
	Residual	0.5251	12	0.0438		
	Cor total	8.69	17			
$R^2 = 0.9396$; Adj $R^2 = 0.9144$; Pred $R^2 = 0.8595$; Adeq precision = 19.9210						
WAC	Model	46.05	3	15.35	100.13	< 0.0001*
	Residual	2.15	14	0.1533		
	Cor total	48.19	17			
$R^2 = 0.9555$; Adj $R^2 = 0.9459$; Pred $R^2 = 0.9278$; Adeq precision = 32.0024						
AB	Model	1.86	5	0.3716	66.47	< 0.0001*
	Residual	0.0671	12	0.0056		
	Cor total	1.92	17			
$R^2 = 0.9652$; Adj $R^2 = 0.9506$; Pred $R^2 = 0.9051$; Adeq precision = 27.2597						

*Significant at $p < 0.05$ (5%)

Table 2: ANOVA of 225 mm HSB

Responses	Source	Sum of square	df	Mean square	F ratio	p value
Density	Model	2.228E+05	5	44560.64	103.34	< 0.0001*
	Residual	5174.43	12	717.75		
	Cor total	2.280E+05	17			
$R^2 = 0.9773$; Adj $R^2 = 0.9678$; Pred $R^2 = 0.9481$; Adeq precision = 36.0134						
CS	Model	14.07	5	2.81	68.43	< 0.0001*
	Residual	0.4935	12	0.0411		
	Cor total	14.56	17			
$R^2 = 0.9661$; Adj $R^2 = 0.9520$; Pred $R^2 = 0.9281$; Adeq precision = 25.5206						
WAC	Model	59.39	5	11.88	34.08	< 0.0001*
	Residual	4.18	12	0.3486		
	Cor total	63.58	17			
$R^2 = 0.9342$; Adj $R^2 = 0.9068$; Pred $R^2 = 0.8706$; Adeq precision = 19.6390						
AB	Model	0.9593	5	0.1919	65.34	< 0.0001*
	Residual	0.0352	12	0.0029		
	Cor total	0.9945	17			
$R^2 = 0.9646$; Adj $R^2 = 0.9498$; Pred $R^2 = 0.9022$; Adeq precision = 26.7775						

*Significant at $p < 0.05$ (5%)

Expert 13.0, 2021; Anifowose et al., 2024b; Odeyemi et al., 2024).

The Three-Dimensional (3D) response surface plots that estimate the optimum values for the two factors considered are shown in Figures 5; 6; 7; 8; 9; 10; 11, and 12 for Density-150 mm, CS-150 mm, WAC-150 mm, AB-150 mm, Density-225 mm, CS-225 mm, WAC-225 mm, and AB-225 mm, respectively. The colour spectra represent the intensity of the responses in both types of curves with the blue regions and the red regions indicating the lowest and the highest response values, respectively (Abdulkadir et al., 2021; Jhatial et al., 2021;

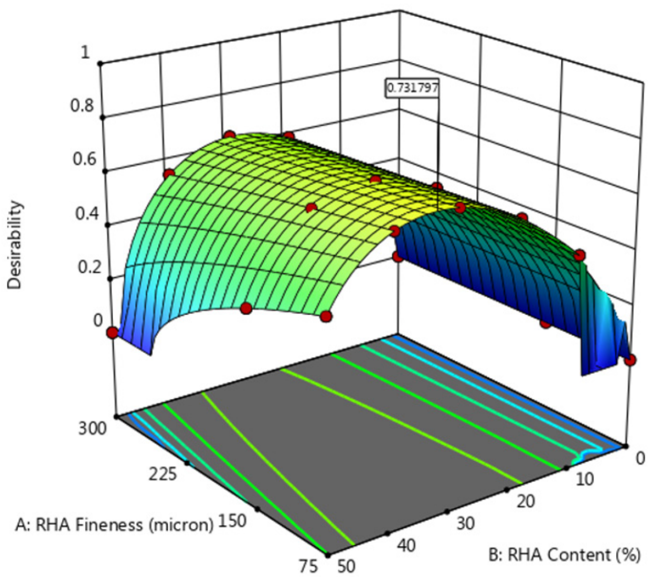

Figure 5: Response surface plot of 150 mm Density

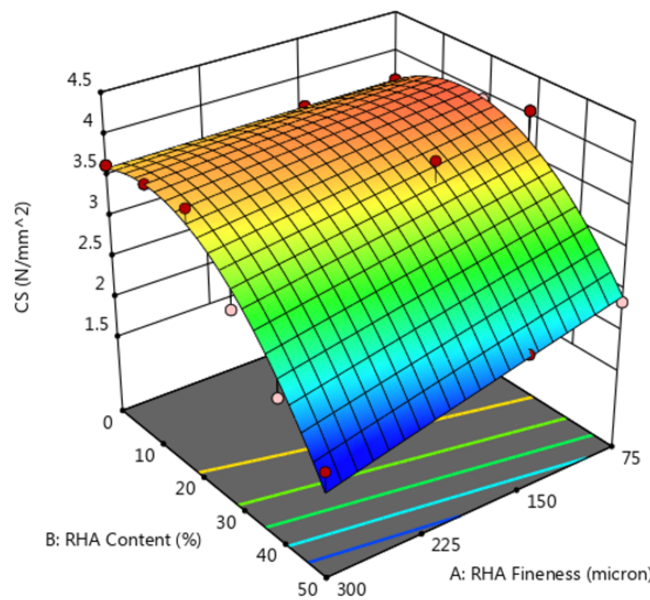

Figure 6: Response surface plot of 150 mm CS

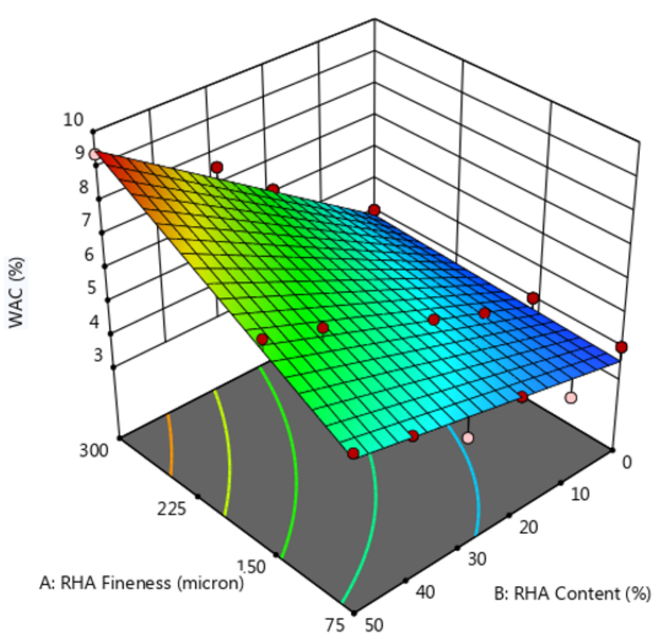

Figure 7: Response surface plot of 150 mm WAC

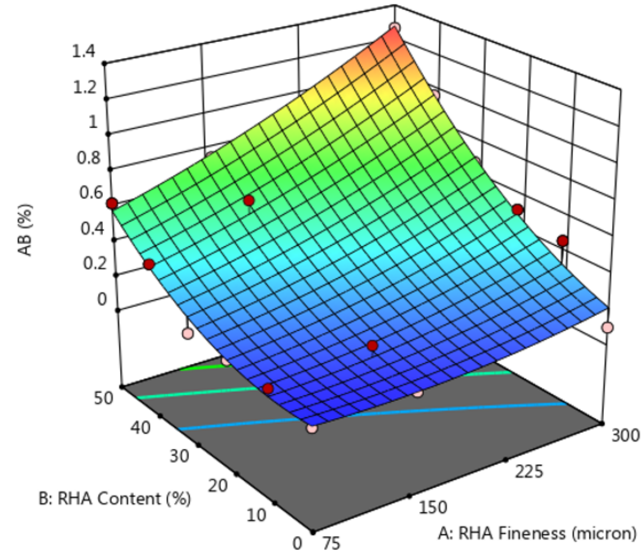

Figure 8: Response surface plot of 150 mm AB

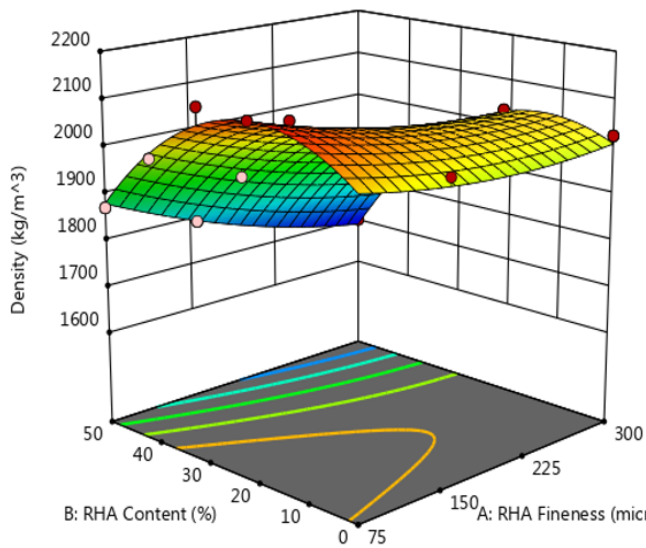

Figure 9: Response surface plot of 225 mm Density

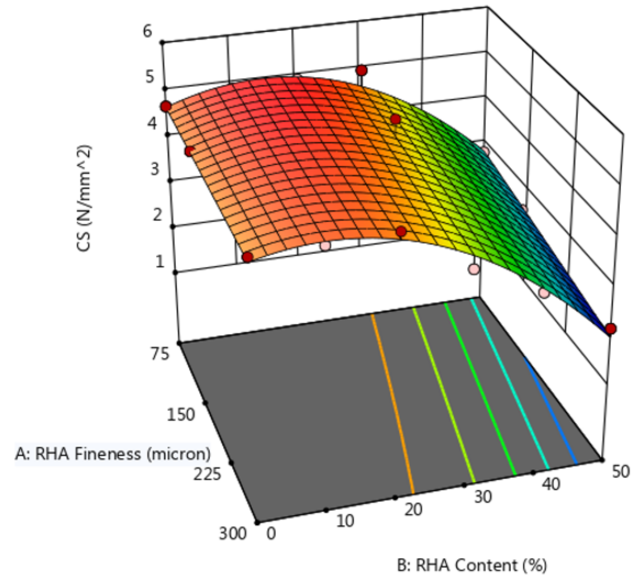

Figure 10: Response surface plot of 225 mm CS

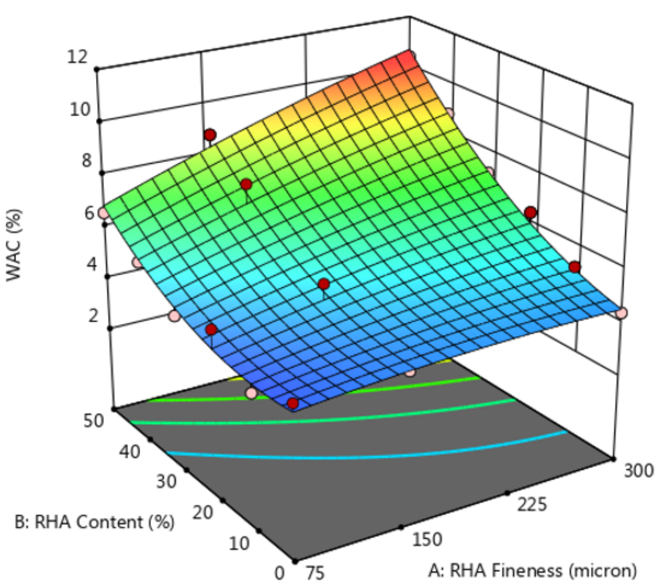

Figure 11: Response surface plot of 225 mm WAC

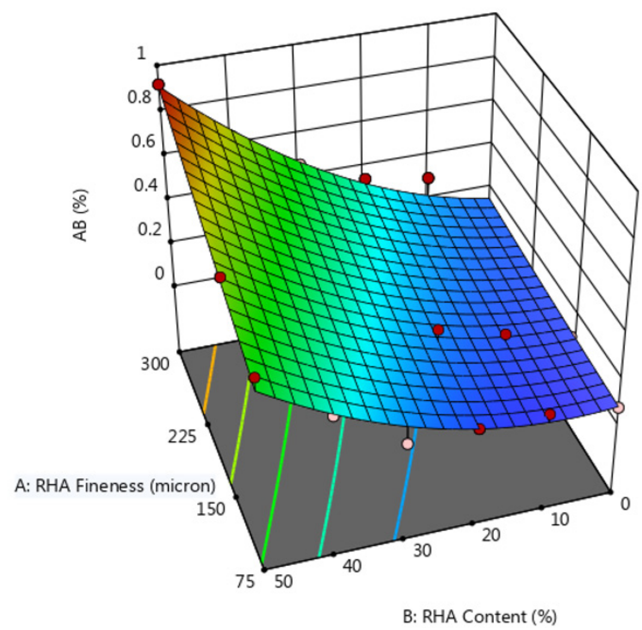

Figure 12: Response surface plot of 225 mm AB

Amin et al., 2022; Khalid et al., 2024; Abdulwahab et al., 2025).

The predicted versus actual experimental plot for the developed response models are as presented in Figures 13a – 16b. This plot is one of the important diagnostic tools used for the assessment of the adequacy of a model. For a good fit, the data points for the plot of predicted versus actual should align to the fitted line (straight line) as much as possible (Adamu et al., 2024; Turkane et al., 2024). As evident from all the plots in this research, the predicted values are as close to the actual values as possible due to their diagonal alignment around the fitted line. This is a good indication of the quality of the response models. This finding was corroborated

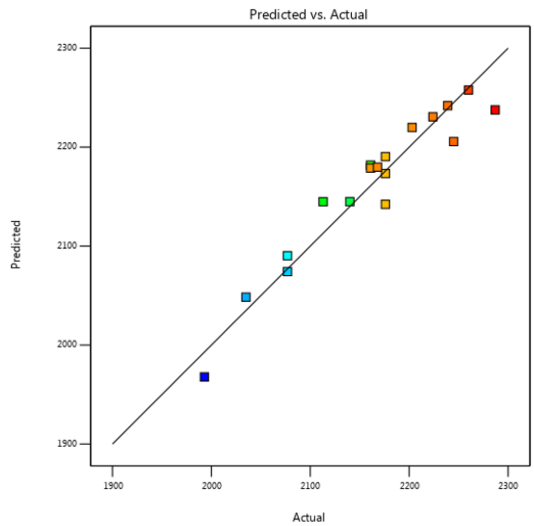

Figure 13a: Predicted density versus actual density plot of 150 mm HSB

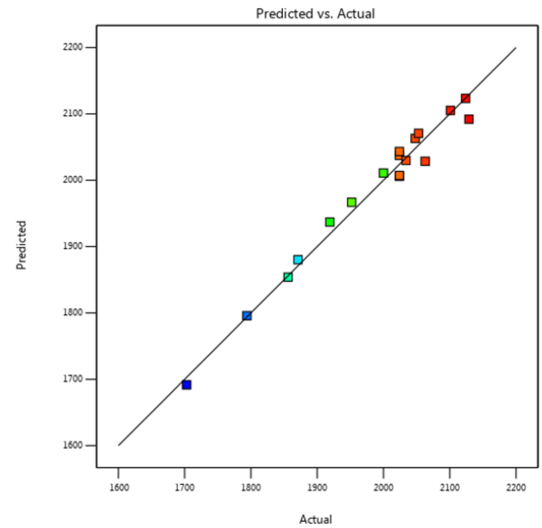

Figure 13b: Predicted density versus actual density plot of 225 mm HSB

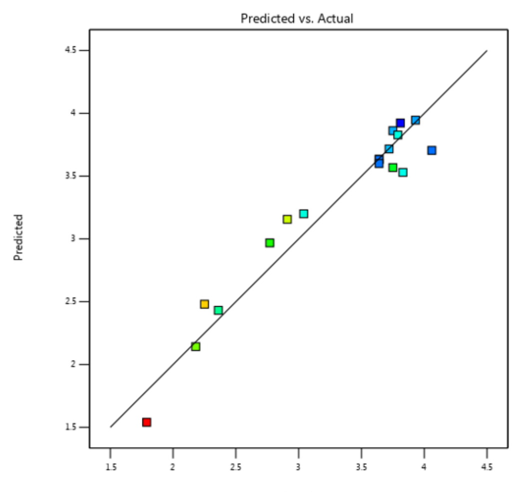

Figure 14a: Predicted CS versus actual CS plot of 150 mm HSB

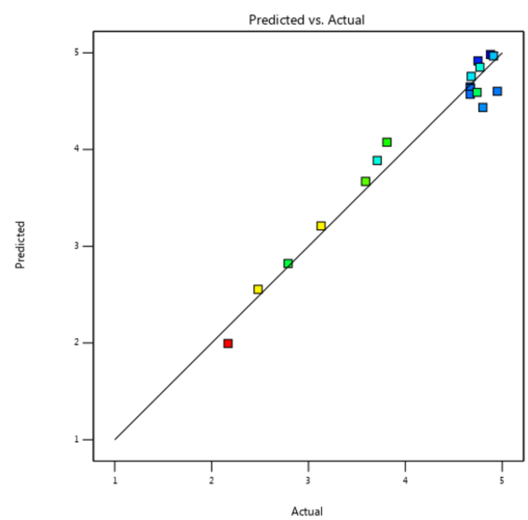

Figure 14b: Predicted CS versus actual CS plot of 225 mm HSB

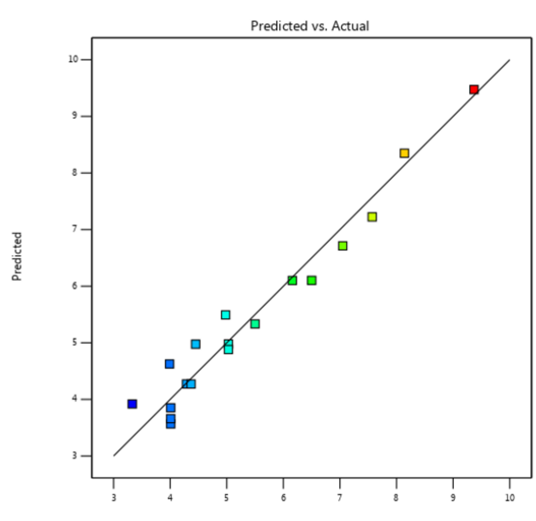

Figure 15a: Predicted WAC versus actual WAC plot of 150 mm HSB

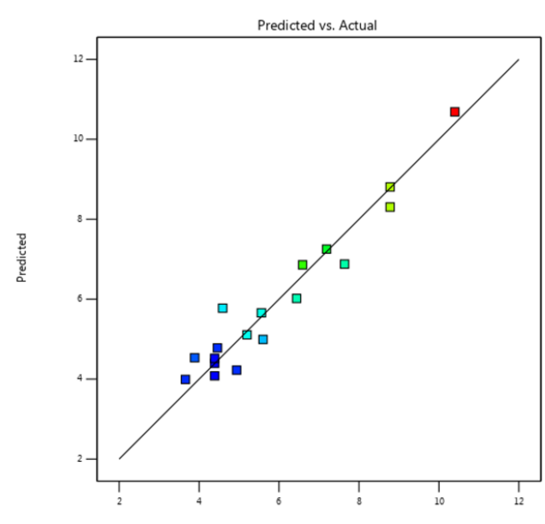

Figure 15b: Predicted WAC versus actual WAC plot of 225 mm HSB

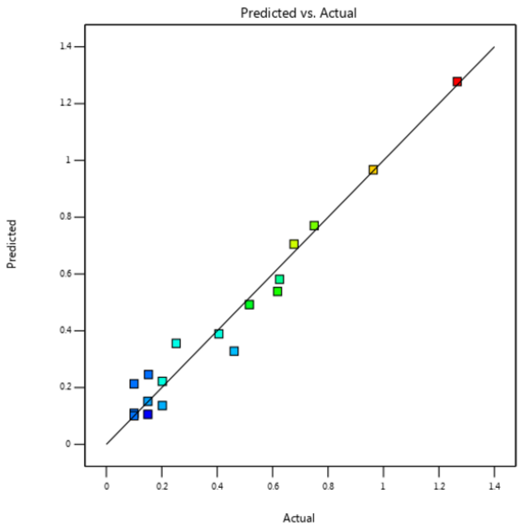

Figure 16a: Predicted AB versus actual AB plot of 150 mm HSB

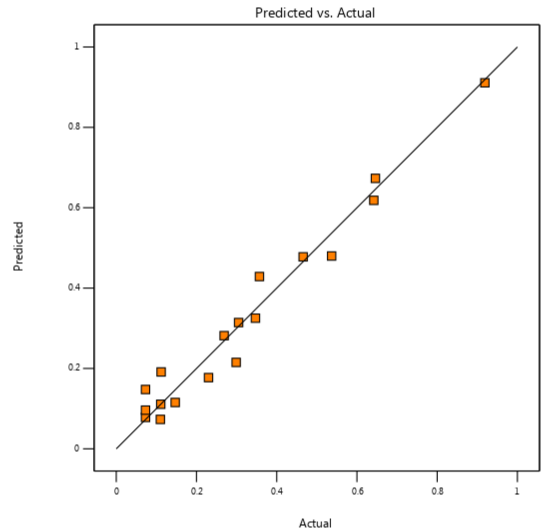

Figure 16b: Predicted AB versus actual AB plot of 225 mm HSB

by Abdulkadir et al., (2021), Akanbi et al., (2022), and Zhang et al., (2025).

4. CONCLUSIONS

Prediction of the optimum content of RHA as substitute of PLC in producing Hollow Sandcrete Blocks, towards sustainability was investigated, thereby leading to the following conclusions:

1. The optimum replacement of PLC with RHA predicted by the model for producing hollow sandcrete blocks was obtained at 34.6283 and 33.5044 %, for 450 x 150 x 225 mm and 450 x 225 x 225 mm blocks, respectively.
2. The relationship between the predicted values (for the developed response models) and the actual experimental values indicate a good quality of the response models.
3. The ANOVA of the models for the variables (RHA fineness and contents) indicated a significant level at $p < 0.0001$ (which is less than 0.05) for all the responses (Density, CS, WAC and Abrasion), which proved that the models were significant.
4. The optimum response values of the models predicted through the response surface methodology proved reasonable reduction in PLC usage for HSB production without affecting properties (Density, CS, WAC and AB) of the HSB.
5. Application of 34% RHA as substitute of PLC in HSB could lead to sustainable HSB through waste minimization, thereby maintaining quality of HSB properties in line with Nigeria Industrial Standard.

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