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Comparative Analysis of Statistical Models for Predicting the Properties of Agricultural Waste-Enhanced Sandcrete Blocks

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ABSTRACT

Sandcrete blocks represent an indispensable building material, primarily composed of sand, water, and cement as a binding agent. Given the significant cost associated with cement, there is a need to produce low-cement blocks that are economically viable and cost-effective. This challenge has prompted the exploration of alternative materials to reduce cement content, simultaneously addressing environmental pollution and health risks associated with agricultural waste in rural areas. Notable examples of such alternative materials include various agricultural waste components. The primary objective of this research is to establish statistical models for predicting the compressive strength of blocks reinforced with rice husk, guinea corn husk, maize straw, and a combination of sorghum husk and straw. The research findings indicate that the density of fibre-reinforced blocks decreased as the quantity of fibre increased. Furthermore, the compressive strength of the sandcrete blocks decreased as the fibre content increased. However, compressive strengths of 2.41 N/mm², 1.90, 2.40 N/mm², and 3.01 N/mm² were achieved for rice husk, guinea corn husk, maize-straw, and a combination of sorghum husk and straw-reinforced sandcrete blocks, respectively. Only sandcrete blocks with sorghum husk and straw met the Nigerian Industrial Standard specifications (NIS 87:2000). A water-binder ratio of 0.4 was determined as optimal for all the blocks under investigation. Four models with precision values higher than 4.0 were generated to predict the compressive strengths of the blocks. This research represents a valuable contribution to developing environmentally friendly building materials for the construction industry.

Keywords: Agricultural waste; Sandcrete blocks; Statistical models; Straw.

INTRODUCTION

Sandcrete blocks have been used in all types of masonry constructions in Nigeria, and other parts of the world. Over 90% of physical infrastructures in Nigeria are made with sandcrete blocks (Erakpoweri and Onah, 2022a). The usual requirement for a good sandcrete is its satisfactory compressive strength, however, research has shown that the compressive strength of sandcrete produced commercially in several parts of Nigeria, is below the recommended standard as stipulated in the Nigerian Industry Standard (NIS 87:2000, 2000). According to Anosike and Oyebade (2012) and Ajao et al. (2018), sandcrete manufacturers in Nigeria do not adhere to the guidelines for sandcrete production as stipulated by the Standard, and this could be traced to poor implementation and monitoring on the part of the Standard Organization of Nigeria (SON) to ensure adherence to the code (Erakpoweri and Onah, 2022a). Sandcrete blocks are made of natural sand, water, and a binder. The costliest component in the production of sandcrete blocks is cement, which is the binder (Awolusi et al., 2021). Utilizing alternative stabilizers made from less expensive local materials will greatly enhance the production of sandcrete blocks with the desired properties at a low cost. In addition, it will significantly reduce construction costs and production costs (Alejo, 2020).

Rice husk (RH) has distinct physical and chemical characteristics, such as a high ash and silica content, making it useful for industrial processing. Numerous studies have demonstrated the use of RH as fuel for a variety of purposes (Kaviyarasu et al., 2016; Shen et al., 2014). Oyetola et al. (2006) and Khan et al. (2021) studied the possibility of using Rice Husk Ash (RHA) in the production of sandcrete blocks and reported that the water/cement ratio increases with rice husk ash contents and that up to 40% RHA could be added as a partial replacement for cement without any significant change in compressive strength at 60 days and 28 days respectively.

Maize straw fibre is a natural and renewable agricultural by-product derived from the stalks of maize (corn) plants. It is a versatile and eco-friendly material that has gained attention in various industries, including construction, packaging, and textile (Rahman et al., 2023; Saba et al., 2015). Various studies have been conducted using maize straw fibre in engineering; Odeyemi et al. (2022) conducted a study on maize straw-reinforced sandcrete blocks and found that incorporating 5% maize straw resulted in the highest compressive strength after 28 days. This strength was found to meet the recommendations of the Nigerian Industrial Standard. Odeyemi et al. (2017) investigated the effect of straw reinforcement on clay bricks. Their study revealed that adding straw to clay bricks at a water-clay mixing ratio of 0.15 increased the compressive strength of the bricks by 148%.

Guinea corn husks are byproducts remaining after the extraction of guinea corn seeds. These husks typically end up as non-biodegradable waste in landfills, contributing to environmental pollution (Adediran et al., 2019). Odeyemi et al. (2020) conducted a study to assess how guinea corn ash influenced the mechanical attributes of lateritic concrete when used as a substitute for Ordinary Portland Cement (OPC). The most effective blend was determined to be 20% Guinea Corn Husk Ash (GCHA) combined with 80% OPC, which yielded an elevated compressive strength of 18.78 N/mm^2.

Sorghum, comprising 25 species of flowering plants, is a robust grass that can reach heights of up to 4.6 meters (Xiong et al., 2019). Information obtained from Statista (2023) indicates that Nigeria ranks as the world's second-largest sorghum producer, generating an annual production of 6.7 million metric tons (Oladehinde Oladipo, 2023). Tijani's (2020) research delves into the utilization of Sorghum Husk Ash (SHA) as a viable substitute for cement in the production of sandcrete blocks. The inclusion of SHA is found to enhance compressive strength while maintaining an acceptable level of block density and water absorption.

Though researchers have studied the use of straw and ashes in sandcrete blocks, there are no results on the optimization of these straws in the blocks nor are there models that can predict the strength of the blocks containing the straws. To bridge this gap, this research developed statistical predictive models for the compressive strength of agricultural waste-enhanced sandcrete blocks.

MATERIALS AND METHODS

This section enumerates the materials used and the methods adopted in getting the results for this research.

Materials

Portland Limestone Cement (PLC) of Dangote cement brand with grade 42.5R which complied with BS 8500-1 (2023) was used. The Sharp sand, which conformed to the specifications in BS EN12620 (2013) was locally sourced from Malete, Kwara state, Nigeria. The potable water used was free from impurities. Rice husk, Sorghum husk, Guinea corn husk, maize and sorghum straws were sourced locally from Oja Oba, Ilorin, Kwara state, Nigeria. The straws were broken into small sizes of about 10 centimetres.

Mix proportion

The experiment was designed using the Design Expert software package (Version 13) to optimize the agro waste (ranging from 5% to 10%) and the water-cement ratio (from 0.4 and 0.6) through a Response Surface Methodology (RSM) within a Central Composite Design (CCD). The agro-waste materials were incorporated into the sandcrete mix of ratio 1:6 (cement-to-sand ratio). Before conducting the laboratory experiments, combinations were systematically designed as required by CCD. In the first part of the study, two independent variables were considered: the specific agro-waste materials (Guinea corn husk, rice husk, and maize straw fibre) and the water-cement ratio. This led to 13 experimental runs aimed at measuring compressive strength. In another part of the study, a similar procedure was followed for a combination of sorghum husk and straw with a fixed water-cement ratio. This part produced 14 experimental runs to assess the compressive strength, water absorption, and density of the sandcrete block. Figure 1 shows a typical designed experiment interface in the Design Expert software package.

A manual method of mixing was adopted in producing the blocks of 225 mm × 225 mm × 450 mm size. Afterwards, the blocks were cured for 28 days by full immersion in water before testing for their strengths.

Property determination

The density of each block was calculated by finding the fraction of the volume of the blocks to its weight following BS EN 772- 13 (2000) as shown in (Eq. 1).

$$\text{Density} = \frac{\text{Weight of the block (kg)}}{\text{Volume of block (m}^3\text{)}} \quad (1)$$

The strengths of the blocks were determined using a STYE-2000 Analogue type compression testing machine with serial number 131010 (Figure 2) supplied by Okhard Machine Tools, Lagos, Nigeria at the Kwara State Ministry of Works' Works and Transport laboratory, Ilorin, Nigeria.

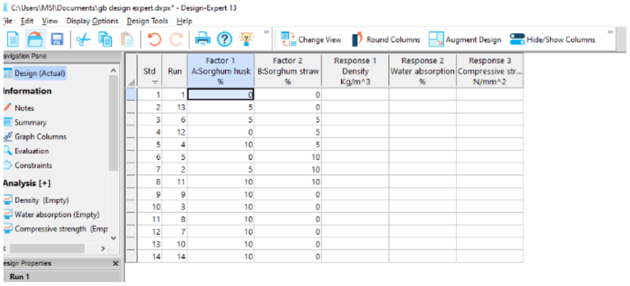


Figure 1. Design interface for Sorghum husk and sorghum straw.

Figure 2. Compressive strength test

The compressive strength was determined using (Eq. 2).

$$\text{Compressive strength} = \frac{\text{Maximum load (kN)} \times 1000}{\text{Cross- sectional Area (mm}^2\text{)}} \quad (2)$$

The water absorption capacity for the blocks was determined at the concrete laboratory of the Department of Civil Engineering, Kwara State University, Malete, following the specifications in BS EN 772-21 (2011) and calculated using (Eq. 3).

$$\text{Water absorption (\%)} = \frac{M_w - M_d}{M_d} X\ 100 \quad (3)$$

Model formulation

The statistical models were constructed using the Design Expert software package utilizing the multiple linear regression technique. As illustrated in (Eq. 4), the models depict a relationship involving Y, X_1, and X_2:

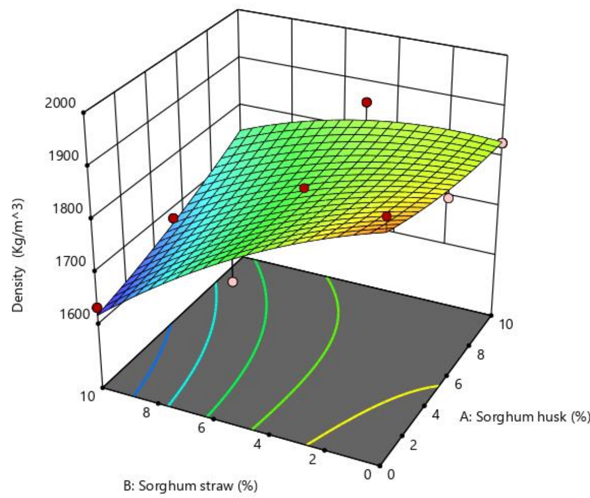
$$Y = a + bX_1 + cX_2 + \epsilon \quad (4)$$

Y represents the dependent variable, X_1 and X_2 represent the independent variables, ϵ represents the error term, while a, b, and c are the coefficients within the regression equations (Erakpoweri & Onah, 2022b).

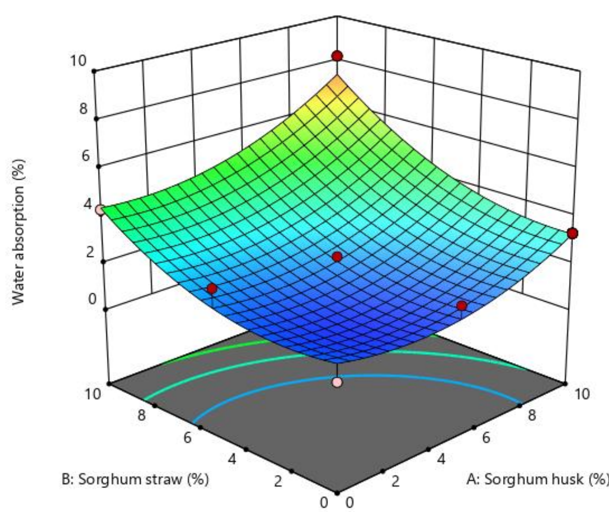
RESULTS AND DISCUSSIONS

Density result

Graphs 1 and 2 show the 3D relationship between the sorghum husks and straws with density and water absorption respectively. The graphs reveal that increasing the volume of both husk and straw in the blocks led to a reduction in the density and an increase in the water absorption capacities of the blocks. These results conform with the submission of Odeyemi et al. (2021).



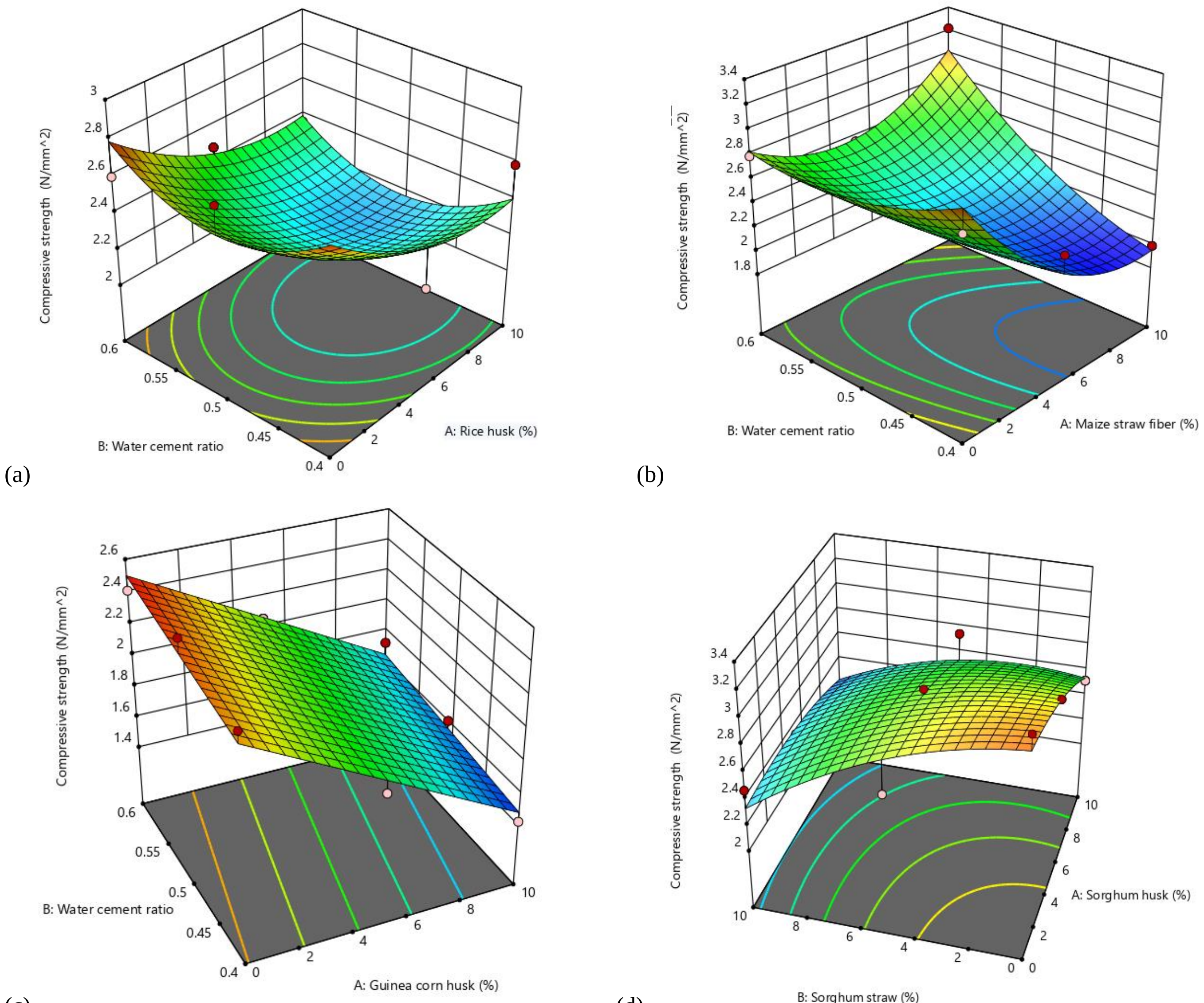
Graph 1. Relationship of sorghum husks and straws with density



Graph 2. Relationship of sorghum husks and straws with water absorption

Compressive strength results

Graphs 3 (a-d) depict the relationship between water-cement ratio, volume of agro waste and compressive strength for rice husk, maize straw fibre, guinea corn husk, sorghum husk and straw respectively. The addition of the straws in the blocks adversely affected the strength of the blocks. This could be due to the straws taking up some of the spaces that the sandcrete mortar could have occupied. The increase in the water-cement ratio equally led to a decline in the strength of the blocks. This is consistent with results from the literature (Neville, 2011; Odeyemi, 2021).



Graph 3. Relationship between water-cement ratio, agro waste and compressive strength (a) rice husk (b) maize straw fibre (c) guinea corn husk (d) sorghum husk and straw

Table 1. Optimized values of agro-waste incorporation in sandcrete blocks

Agro-waste	Quantity (%)	Water-cement Ratio	Density	Water absorption	Compressive Strength	Desirability (%)
Rice Husk	10	0.4	-	-	2.41	100
Guinea corn husk	4.70	0.4	-	-	1.90	59
Maize straw	10	0.4	-	-	2.40	78
Sorghum Husk	4	0.4	1841	1.75	3.01	81
Sorghum straw	6					

Optimization

From the 28th-day results for the blocks containing the various straws, an optimization process was conducted on the sandcrete blocks. The goal was to maximize the rice husks/straw content and compressive strength while minimizing the water-cement ratio. The optimized combination, strength obtained and the desirability value are presented in (Table 1). The optimized chart for the combined sorghum husk and straw sandcrete is shown in Figure 3. Only sandcrete blocks with sorghum husk and straw met the Nigerian Industrial Standard (NIS 87:2004, 2004) specifications for non-load bearing walls. However, the reported strengths are higher than the ones produced by the eight block industries reported by Odeyemi et al. (2018).

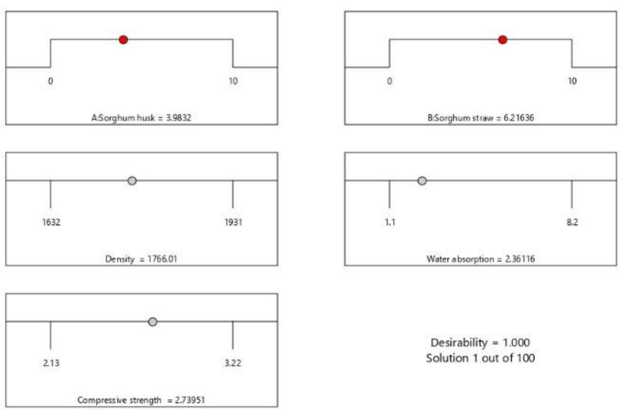


Figure 3. Optimization of sorghum husk and straw

Model equations

Equations 5-8 relate the compressive strength to the various agro-wastes and water-cement ratios.

$$C = 8.2478 - 0.0946R - 22.75W - 0.005RW + 0.0058R^2 + 22.75W^2 \quad (5)$$

$$C = 3.10 - 0.023H - 0.015S + 0.0046HS - 0.0034H^2 - 0.0062S^2 \quad (6)$$

$$C = 7.54 - 0.52M - 17.6W + 0.675MW + 0.0138M^2 + 16.25W^2 \quad (7)$$

$$C = 0.6477 - 0.1728G + 7.1846W + 0.15GW + 0.0012G^2 - 7.0W^2 \quad (8)$$

Where C = Compressive strength, R, H, M and G = Percentage of rice, sorghum, maize and guinea corn husks respectively, S = Percentage of sorghum straw and W = Water-cement ratio.

Model validation

All the models yielded a precision value higher than 4.0 (Table 2), indicating a satisfactory signal-to-noise ratio. This suggests that the models are dependable for guiding design exploration, thus validating the models.

Table 2. Fit statistics of all the models

Statistical parameter	Rice husk	Sorghum husk and straw	Guinea corn husk	Maize straw fibre
Adeq Precision	5.76	10.9761	33.3233	5.75

CONCLUSIONS

The following conclusions are made from this research:

1. The addition of rice, sorghum, guinea corn maize husks and sorghum straw lowers the compressive strength of sandcrete blocks.
2. Optimized strengths of 2.41 N/mm^2, 1.90 N/mm^2, 2.40 N/mm^2, 3.01 N/mm^2, were obtained for sandcrete blocks containing rice husk, guinea corn husk, maize straw and sorghum husk combined with sorghum straw respectively.
3. The strengths of sandcrete blocks containing rice, guinea corn, maize straw husks, and sorghum husks combined with sorghum straw were predicted using statistical models.

DECLARATIONS

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Authors' contribution

The first author developed the concept for the research and designed the experimental process. The second author assisted in the design of the experimental process and writing the manuscript. The third, fourth, fifth and sixth authors carried out the bench work and wrote the draft manuscript. Both the first and second authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests in this research and publication.

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