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Modelling and Optimization of Mass Density for Strength and Durability of Sandcrete Block from Okhuare in Edo State, Nigeria

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ABSTRACT: The compressive strength of sandcrete block is a very important aspect of a block in a building. In many cases of building failures in Nigeria, the strength of the sandcrete block, has been figured as one of the causes of the failure. Hence the objective of this paper was to model and optimize the mass density for strength and durability of sandcrete block from okhuare in Edo State, Nigeria using standard methods. The mass of block was minimized, density was maximized, failure load was maximized, water absorption was minimized and compressive strength was maximized. Mass is 27.3287, density is 2149.19, failure load is 234.861, water absorption is 6.60831 and compressive strength is 4.08817. The optimum value of process parameters were determined. Water is 0.56, cement is 0.42, sand is 10.00.The experiment was performed and the results accurately measured and a mathematical model that can adequately explain the effects of the process parameters on the strength and durability of the sandcrete block was developed and the most significant factor influencing the strength of the block was identified.

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Sandcrete blocks are composite material made up of sand, cement and water moulded into different sizes (Barry 1969). Nigerian Industrial Standard (NIS): 87 2004) defined sandcrete as a composite material made up of sand, cement and water. Sandcrete blocks are by far the most common type of block used in modern day construction in Nigeria. Their major advantages as compared to the other types of block are their easy mode of production and the speed of laying. Their major setback is their poor thermal and hygrometric properties. This can greatly affect the strength and durability of the composite material. In order to improve on these remarkable properties, the walls formed with sandcrete blocks are usually rendered with cement and sand mortar. Sandcrete blocks are classified as solid and hollow blocks. Solid blocks have no cavities while Hollow blocks have cavities in them. Sandcrete blocks are traditionally made of a mixture of sand (fine aggregates), cement and water. Recent practice in sandcrete block production often includes the partial replacement of the sand with quarry dust or with coarse aggregates. This has been found to improve on the strength and the durability of the blocks. Anosike and Oyebade (2012) reported that the NIS specified two types of blocks, type A and type B. Type A block is load bearing while type B blocks are non- load bearing. Both of them can either be solid or hollow. Sandcrete blocks are relatively cheap as

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compared to other construction materials. They have a high resistance to damage. Sandcrete blocks do not decay, rust or provide a home for damaging insects as in other materials (Odeyemi, 2012). Oyetola and Abdullahi (2006) argued that sandcrete has been in use throughout West Africa for over five decades as a popular building material for preparation of building blocks and bricks (Aiyewalehinmi and Tanimola 2013). Okoli, *et al* (2008) argued that apart from manufacturers and entrepreneurs who are producing block strictly for business purposes, quite a number of contractors and clients are also making blocks for use on their projects. Oyekan and Kamiyo (2011) added that this comes with great challenge in Nigeria due to the large size of the block manufacturing industry. Chandrasekhar (2003) argued that sancrete is the main building material used for the construction of walls of most post independent building in Nigeria. Samson (2002) state that quality and standardization of sandcrete blocks are of paramount importance in the study of building components. These will serve as standards for measurement which reflect the level of development attained by a nation. Hence the objective of this paper was to model and optimize mass density for strength and durability of sandcrete block from Okhuare in Edo State, Nigeria

MATERIALS AND METHODS

Materials: The materials used for this work are (i) Cement (ii) Water (iii) Sand

Cement: Cement obtained from a major cement dealer in Edo state was used for all the tests.

Water: Potable water conforming to the specification of EN 1008: (2002) was used for both specimen preparations and curing.

Sand: Sand obtained from Okhuare in Edo State of Nigeria was used.

Design of experiment: The experimental design used was the central composite design, which was developed by the design expert software

Central Composite Design: The number of components is 3 and a second degree polynomial was used in designing the experiments. $N=2^n+2n+k$. The experiment was designed with design expert software

Experimental investigation: The experimental works involved both field works and laboratory works

Field work: The field work was on the production of the blocks. The blocks were produced using an egg laying machine. Mixing of the constituents was done manually. First, the sand and the cement was mixed .Water was finally added and the mixing continued until the colour of the paste was uniform. The mixture was then loaded into the moulds of the machine where they were vibrated, compacted and demoulded immediately. All the blocks were cured, under shade, for twenty eight days by sprinkling them with potable water twice daily. The compressive strength, water absorption, mass and density of the block were measured.

RESULTS AND DISCUSSION

In this study, twenty experimental runs were carried out, each experiment considered the water ratio, cement ratio, sand ratio, mass of block, density, compressive strength, water absorption and failure load. The experimental results is shown in table 1.

Table 1: Experimental Results

Water	Cement	Sand	Mass (Kg)	Density (kg/m^3)
0.5200	1.0000	5.4000	27.9600	2162.0000
0.8000	1.0000	3.8000	27.2900	2131.0000
0.6300	1.0000	5.0000	27.5300	2143.0000
0.7400	1.0000	5.2000	26.8900	2125.0000
0.7200	1.0000	4.7000	27.5300	2110.0000
0.8600	1.0000	6.0000	26.9000	2122.0000
0.7500	1.0000	7.1000	27.2000	2107.0000
0.8700	1.0000	7.4000	27.0000	2118.0000
0.7500	1.0000	5.4000	27.4000	2128.0000
0.7300	1.0000	6.7000	27.9000	2167.0000
0.6800	1.0000	7.7000	26.8000	2115.0000
0.5200	1.0000	6.4000	28.0000	2186.0000
0.6100	1.0000	4.8000	27.0000	2122.0000
1.0000	1.0000	7.4000	26.0000	2111.0000
0.7600	1.0000	6.0000	27.0000	2120.0000
0.6350	1.0000	5.4000	28.0000	2187.0000
0.5100	1.0000	6.9000	27.0000	2175.0000
0.5600	1.0000	5.5000	28.0000	2152.0000
0.6600	1.0000	6.3000	25.9000	2175.0000
0.5600	1.0000	5.8000	23.9000	2133.0000

Modelling and Optimization of Okhuare block process parameters: In this study, a mathematical model was developed to optimize mass density with selected input variables, using response surface methodology (RSM)

The objectives of the model was to minimize mass of block and also to maximize density of the sandcrete blocks for strength and durability.

Model development for Okhuare Sand: For the development of the models certain statistical test has to be passed which includes the sequential sum of square,lack of fit test, model summary statistics,ANOVA and goodness of fit . the result for the goodness of fit for the mass of the block is shown in table 2. Sequential sum of square shown in Table 3 was also determined for the density of the block,this test help us to select the best model suitable for the block making process parameters. The next step taken was to ascertain the best model fit for the process paramaters.In this case lack of fit test was carried out for determining required p-value,a non-significant lack of fit p> 0.05 was obtained. The results for the mass of block is presented in table 4. The lack of fit test was also conducted for the density response which is shown in table 5.

Table 2: Sequential sum of square for mass of block

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	14644.87	1	14644.8700			
Linear vs Mean	5.0100	3	1.6700	2.1600	0.7954	
2FI vs Linear	0.5900	3	0.2000	0.2200	0.9234	
Quadratic vs 2FI	**3.1600**	**3**	**1.0500**	**1.2200**	**< 0.0001**	**Suggested**
Cubic vs Quadratic	2.1100	4	0.5300	0.4900	0.4984	Aliased
Residual	6.5100	6	1.0900			
Total	14662.26	20	733.11			

Table 3: Sequential sum of square for density of block

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	9.154E+007	1	9.154E+007			
Linear vs Mean	1670.3800	3	556.7900	0.7500	0.5406	
2FI vs Linear	680.5000	3	226.8300	0.2600	0.8518	
Quadratic vs 2FI	**601.2300**	**3**	**200.4100**	**0.1900**	**< 0.0001**	**Suggested**
Cubic vs Quadratic	4901.6200	4	1225.4100	1.2700	0.3757	Aliased
Residual	5767.2200	6	961.2000			
Total	9.154E+007	1	9.154E+007			

Table 4: Lack of fit test for mass

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Linear	10.1900	11	0.9300	2.1100	0.1180	
2FI	9.5900	8	1.2000	2.7300	0.1280	
Quadratic	**6.4300**	**5**	**1.2900**	**2.9300**	**0.1316**	**Suggested**
Cubic	4.3200	1	4.3200	9.8300	0.0258	Aliased
Pure Error	2.2000	5	0.4400			

Table 6: Lack of fit test for density

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Linear	7247.7400	11	658.8900	0.7000	0.1140	
2FI	6567.2400	8	820.9000	0.8700	0.2950	
Quadratic	**5966.0100**	**5**	**1193.2000**	**1.2700**	**0.4002**	**Suggested**
Cubic	1064.3900	1	1064.3900	1.1300	0.3361	Aliased
Pure Error	4702.8300	5	940.5700			

Table 7: ANOVA table for mass of block

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	**8.7600**	**9**	**0.9700**	**1.1300**	**0.0005**	**Significant**
A-water	0.6500	1	0.6500	0.7500	0.4062	
B-cement	1.0300	1	1.0300	1.1900	0.3007	
C-sand	3.3300	1	3.3300	3.8600	0.0778	
AB	0.2900	1	0.2900	0.3400	0.5732	
AC	0.2200	1	0.2200	0.2600	0.6237	
BC	0.0780	1	0.0780	0.0900	0.7698	
A^2	0.0380	1	0.0380	0.0440	0.8376	
B^2	1.1700	1	1.1700	1.3500	0.2714	
C^2	1.6400	1	1.6400	1.9000	0.1979	
Residual	8.6300	10	0.8600			
Lack of Fit	6.4300	5	1.2900	2.9300	0.1316	not significant
Pure Error	2.2000	5	0.4400			
Cor Total	17.3900	19				

In assessing the strength and significance of the quadratic model one way analysis of variance (ANOVA) table was generated for the mass of the block which is presented in Table 7. The analysis of variance which is a test for significance is produced for the density response as shown in table 8. To validate the adequacy of the quadratic model the goodness of fit statistics for mass of the block presented in Table 9..

Table 8: ANOVA table for density of block

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	**2952.11**	**9**	**328.0100**	**0.3100**	**0.0001**	**Significant**
A-water	266.7900	1	266.7900	0.2500	0.6278	
B-cement	834.7800	1	834.7800	0.7800	0.3972	
C-sand	568.8000	1	568.8000	0.5300	0.4820	
AB	128.0000	1	128.0000	0.1200	0.7362	
AC	544.5000	1	544.5000	0.5100	0.4913	
BC	8.0000	1	8.0000	7.498E-003	0.9327	
A^2	170.5300	1	170.5300	0.1600	0.6977	
B^2	341.5900	1	341.5900	0.3200	0.5840	
C^2	40.9900	1	40.9900	0.03800	0.8485	
Residual	10668.8400	10	1066.8800			
Lack of Fit	5966.0100	5	1193.2000	1.2700	0.4002	not significant
Pure Error	4702.8300	5	940.5700			
Cor Total	13620.9500	19				

Table 9: GOF statistics for mass of block

Std. Dev.	0.9300	R-Squared	0.9038
Mean	27.0600	Adj R-Squared	0.8572
C.V. %	3.4300	Pred R-Squared	0.8210
PRESS	51.8100	Adeq Precision	7.6470

Table 10: GOF statistics for density of block

Std. Dev.	32.6600	R-Squared	0.9270
Mean	2139.4500	Adj R-Squared	0.8880
C.V. %	1.5300	Pred R-Squared	0.8212
PRESS	52048.9500	Adeq Precision	14.9090

To validate the adequacy of the quadratic model the goodness of fit statistics for density of the block is presented in Table 10. The optimal equation which shows the individual effects and combine interactions of the selected input variables against the mesured mass of block is presented based on the actual values in Equation 1.

Final Equation in Terms of Actual Factor:

$$Y_m = 27.42863 - 1.181784A - 3.90939B + 0.27715C + 1.19531AB + 0.10391AC + 0.061719BC + 0.32166A^2 + 1.78007B^2 - 0,2109C^2 \quad (1)$$

The optimal equation which shows the individual effects and combine interactions of the selected input variables against the mesured density of block is presented based on the actual values in Equation 2

Final Equation in Terms of Actual Factor:

$$Y_d = 2168.5572 - 82.78675A + 5.71858B + 0.15961C + 25.00000AB + 5.15625AC - 0.62500BC + 21.49959A^2 - 30.42857B^2 - 0.10541C^2 \quad (2)$$

To accept any model, its satisfactoriness must first be checked by an appropriate statistical analysis output, the normal probability plot of residual for the mass of the block is presented in Figure 1. The normal probability plot of residual for the density of the block is presented in Figure 2. To study the effects of water and cement on the mass of the block a surface plot is produced as shown in figure 3.

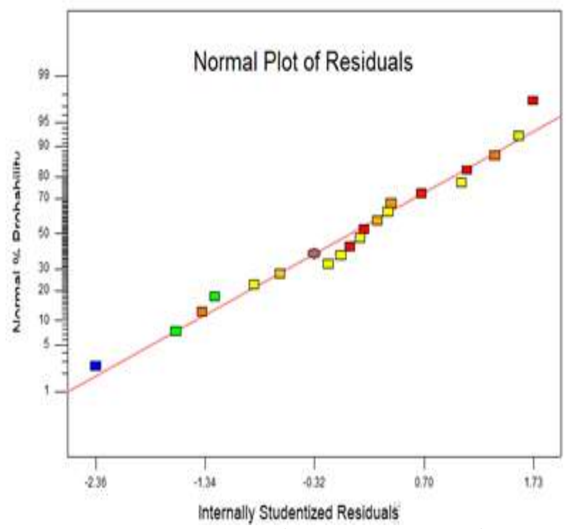

Fig 1: Normal probability plot of studentized residuals for mass of block

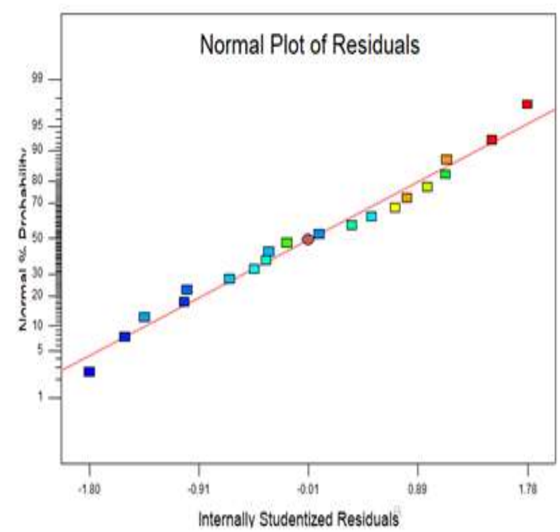

Fig 2: Normal probability plot of studentized residuals for density of block

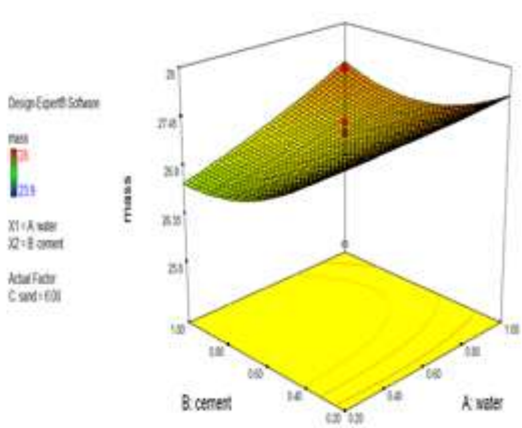

Fig 3: surface plot of cement , Water and mass of block

To study the effects of water and sand on the mass of the block a surface plot is produced as shown in figure 4. To study the effects of water and sand on the mass of the block a surface plot is produced as shown in figure 4

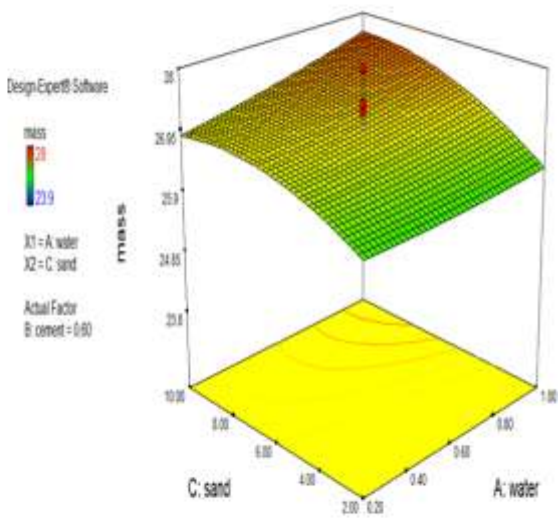

Fig 4: surface plot of sand , Water and mass of block

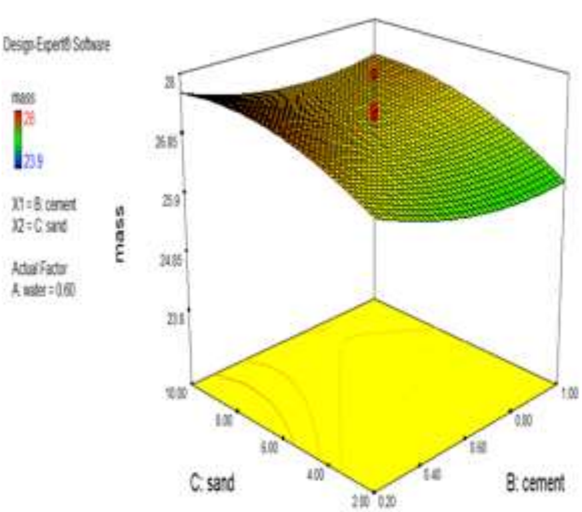

Fig 5: surface plot of sand, Cement and mass of block

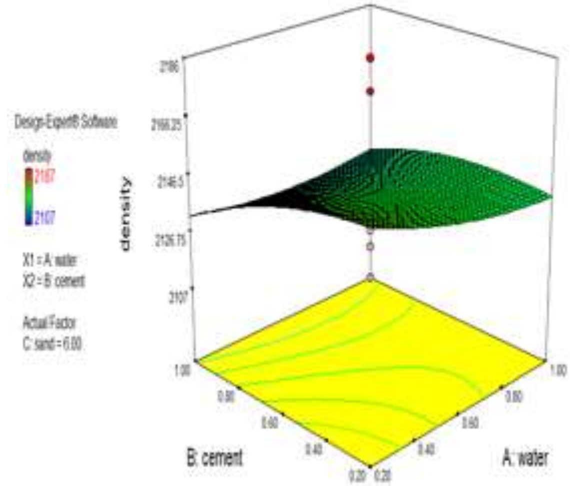

Fig 6: surface plot of Cement, water and density of block

To study the effects of Cement and water on the density of the block a surface plot is produced as shown in figure 7

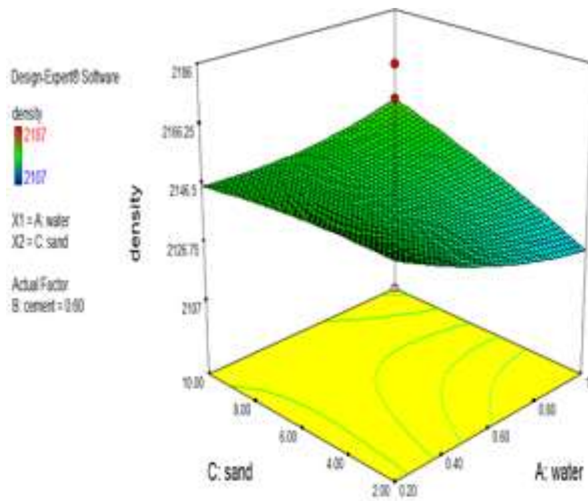

Fig 7: surface plot of sand, water and density of block

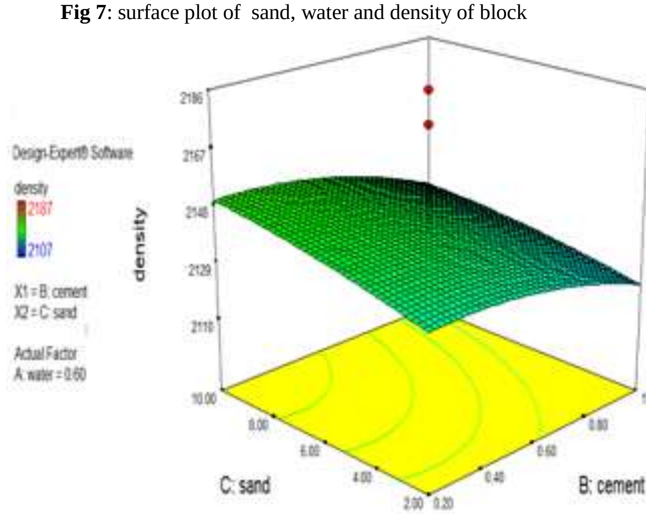

Fig 8: surface plot of sand,cement and density of block

Table 11: The Numerical Optimal Solutions

Water	Cement	Sand	Mass	Density	Desirability
0.5600	**0.4200**	**10.0000**	**27.3287**	**2149.1900**	**0.9490**
0.5700	0.4200	10.0000	27.3352	2149.2400	0.8490
0.5700	0.4100	10.0000	27.3395	2149.2900	0.7490
0.5700	0.4200	10.0000	27.3388	2149.2400	0.6490
0.5900	0.4300	10.0000	27.3387	2149.1800	0.4490
0.5200	0.4000	10.0000	27.3179	2149.2900	0.4490
0.4900	0.4100	10.0000	27.2952	2149.2300	0.4490
0.6500	0.4500	10.0000	27.3665	2149.3600	0.4480
0.4400	0.4100	10.0000	27.2497	2149.1600	0.4470
0.4600	0.4600	10.0000	27.2122	2148.4100	0.4470

To study the effects of sand and Water on the density of the block a surface plot is produced as shown in figure 4. Also a surface plot showing the effects of Sand and Cement on density of the block is produced as shown in figure 8. The numerical solution have been obtained which is presented in table 11

Conclusion: The study has analyzed the process parameters considered in the production of Sandcrete blocks. Samples was collected and block samples were produced using appropriate design of experiment considering the ratio of sand, cement and water as the input process parameters, while the output parameters were mass and density. The experiment was performed and the results accurately measured. A mathematical model that can adequately explain the effects of the process parameters on the strength and durability of the sandcrete block was developed.

Declaration of Conflict of Interest: The authors declare no conflict of interest

Data Availability Statement: Data are available upon request from the first author or corresponding author.

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