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OPTIMIZATION OF COMPRESSIVE STRENGTH FOR MAXIMUM STRENGTH AND DURABILITY OF OKHUARE SANDCRETE BLOCK USING RESPONSE SURFACE METHODOLOGY

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Abstract

This study investigates the compressive strength of sandcrete blocks in Benin. Samples of sand, cement, water and commercial sandcrete blocks were produced. These samples were transported to the laboratory for testing, various test was conducted on the sand, cement and water samples, including failure load, water absorption, mass, density and compressive strength. The blocks were produced using an egg laying machine. Mixing of the constituent was done manually. The mixture was then loaded into the moulds of the machine were they were vibrated, compacted and demoulded immediately. All the blocks were cured, under shade for twenty-eight days. The laboratory investigation was carry out to determine the density, mass, water absorption, failure load and compressive strength of the blocks. To improve the quality of sandcrete blocks produced, Optimization was carry out using response surface methodology with central composite design which generated 20 experimental runs. The mass of block and water absorption were minimized, density, failure load and compressive strength were maximized. Mass is 27.3287kg, density is 2149.19kg/m^3, failure load is 234.861kN, water absorption is 6.60831 and compressive strength is 4.08817N/mm^2 were obtained. The optimum value of process parameters was determined. Water is 0.56, Cement is 0.42, and Sand is 10.00. 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 and statistically justified.

Keywords: Sandcrete Block, Compressive Strength, Durability, Water, Cement, Concrete, Optimization, RSM

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1. Introduction

Sandcrete blocks are traditionally made of cement, natural river sand and water. The constituents are mixed and placed in a mould which is removed immediately after compaction and leveling of the top. The newly produced blocks are self-supporting; hence they are often referred to as zero slump concrete. Individual blocks are joined together, after curing, to form walls using cement-sand mortar. The major advantage of sandcrete blocks is the ease of production and laying of the blocks. The structural properties of blocks of interest include compressive strength, flexural strength, water absorption, modulus of elasticity, shear modulus and split tensile strength. Others are density, fire resistance, durability and thermal conductivity. These properties are dependent to a very large extent on the relative proportions of the constituents and the method of production process. Sandcrete blocks are the most commonly used unit in wall construction in modern Nigeria and, indeed, the entire West Africa. The use of laterite and other forms of walling units, for the construction of modern residential buildings have not made much progress when compared to the use of sandcrete blocks. The same can also be said of bricks. Abdullahi (2005) studied the compressive strength of sandcrete blocks produced in some parts of Minna, Niger state Nigeria and discovered that they were below the minimum NIS standard requirement. Raheem, (2006) considered as assessment of the quality of sandcrete blocks produced by LAUTECH block industry, an area of the business ventures of Ladoke Akintola university of Technology, Ogbomoso, Nigeria. Odeyemi, (2015) observed that the average compressive strength of manually produced blocks and machine compacted blocks at 28th days of curing were 2.83N/mm^2 and 2.96N/mm^2 respectively. Previous research has shown dismal results in the production of sandcrete blocks, which have exhibited compressive strength far below the standard requirement for the construction of houses (Oyekan and Kamiyo 2008). Compressive strength is influenced by the level of quality control employed. Afolayan (2008) opined that a good selection of materials and adequate curing method among others can influence the compressive strength of sandcrete blocks. Strength and durability are two important properties of hardened concrete. Whereas strength can be considered as a short term property, durability is a long term property. These properties are dependent, to a large extent, on the material constituents and the mix proportions, presence of admixtures and the manufacturing process (Oyekan and Kamiyo, 2011).

The compressive strength is by far the most important strength property used to judge the overall quality of concrete. It may often be the only strength property of the concrete that may be determined since with a few exceptions almost all the properties of concrete can be related to its compressive strength. Compressive strength is usually determined by subjecting the hardened concrete, after appropriate curing, usually 28 days, to increasing compressive load until it fails by crushing, and determining the crushing force. Concrete is generally subjected to compressive loads. However, in some instances, such as when used as pavements, they are subjected to flexure. Flexural strength is determined using laboratory test on beam specimens whose lengths are at least times the width and the depth by the so called three-point load method BS EN 12930 – 5 (2009)

Durability is that property of concrete that requires it to Continue to perform its intended functions, that is, maintain its strength and serviceability, during the specified or expected service life (Neville, 2011). Shetty (2005) defined durability of concrete as its ability to resist weathering action, chemical attacks, abrasion, or any other process of deterioration. Mama and Osadebe (2011) developed models, one based on Scheffe's simplex lattice and the other on Osadebe's model, for predicting the compressive strength of sandcrete blocks using alluvial deposit. Osadebe's model was also used by Anyaogu et al (2013) to predict the compressive strength of Pulverized Fuel Ash (PFA) – Cement concrete. Some other works on mixture experiments include: Simon (2003) who developed models for concrete mixture optimization. Models were developed for many responses such as compressive strength, 1-day strength, slump and 42-day charge passed for concrete made using water, cement, silica fume, high range water-reducing admixture, coarse aggregate and fine aggregate. Obam (2009) – a model for optimizing shear modulus of Rice husk ash concrete. Onwuka et al (2011) – model for prediction of concrete mix ratios using modified regression theory. Osadebe and Ibearugbulem (2009) – Simplex lattice model for optimizing compressive strength of periwinkle shell-granite concrete Ezeh and Ibearugbulem (2009, 2010) – models for optimizing compressive strength of recycled concrete and river stone aggregate concrete respectively. This work aim at developing a model to improve the compressive strength of Sandcrete Block using Response Surface Methodology.

2. Materials and Method

2.1Materials

The materials used for this work are (i) cement (ii) Water (iii) Sand. Cement obtained from a major cement dealer in Edo state was used for all the tests. Potable water conforming to the specification of EN 1008: (2002) was used for both specimen preparations and curing. Sand obtained from Okhuare in Edo State of Nigeria was used.

2.2 Design of experiments

The experimental design used was the central composite design, which was developed by the design expert software

The number of components is 3 and a second degree polynomial was used in designing the experiments. $N=2^n+2n+k$

2.3 Experimental investigation

The experimental works involved both field works and laboratory works. The field work was on the production of the blocks. The blocks to be tested for their compressive strength and water absorption were moulded using the ratios in the design matrix. The blocks were produced using an egg laying machine. Mixing of the constituents was done manually using shovels. 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 obtained from the borehole at the site twice daily. The laboratory investigations included all the works and tests that were done in the laboratory to determine the density, water absorption and compressive strength of the blocks.

2.3.1 Physical property test

The sand was tested to determine their bulk densities and gradation (sieve analysis). Collection of samples was in accordance to BS EN 932-1 (1997) while the sieve analysis was in accordance to BS 812 103.1 (2000).

2.3.2 Chemical property tests

Chemical analyses were conducted on the cement and quarry dust to determine their chemical compositions in accordance to USEPA 6200 (2007). Loss on ignition was determined in accordance to BS EN 196 -2 (1995).

2.3.3 Compressive strength

The blocks were crushed after twenty-eight days of curing using Okhard Machine Tool's WA-1000B digital display Universal Testing Machine (UTM). The machine Conforms to the requirements of BS EN 12390-4 (2000) and has a testing range of 0 – 1000kN. The blocks were placed in between two steel plates of 25mm thickness and wide enough as to cover the top and bottom of the blocks. Force was gradually applied through the platens of the testing machine until the block fails in compression. The strengths of the blocks were determined using Equation (1).

Es =1.7ρ2Cs0.33x10-6 (1)

Where Es = Static modulus of Elasticity ρ = density, Cs= compressive strength

3. 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)	Failure Load (kN)	Water absorption	Compressive strength (N/mm^2)
0.5200	1.0000	5.4000	27.9600	2162.0000	255.0000	4.0600	4.4900
0.8000	1.0000	3.8000	27.2900	2131.0000	200.0000	5.4800	3.5000
0.6300	1.0000	5.0000	27.5300	2143.0000	210.0000	5.4100	3.6000
0.7400	1.0000	5.2000	26.8900	2125.0000	205.0000	6.1400	3.3000
0.7200	1.0000	4.7000	27.5300	2110.0000	170.0000	6.0000	2.8000
0.8600	1.0000	6.0000	26.9000	2122.0000	180.0000	6.5300	3.0700
0.7500	1.0000	7.1000	27.2000	2107.0000	155.0000	7.7100	2.7200
0.8700	1.0000	7.4000	27.0000	2118.0000	175.0000	6.8600	3.0000
0.7500	1.0000	5.4000	27.4000	2128.0000	200.0000	8.0000	3.4000
0.7300	1.0000	6.7000	27.9000	2167.0000	263.0000	6.9500	4.6000
0.6800	1.0000	7.7000	26.8000	2115.0000	178.0000	6.0200	2.9000
0.5200	1.0000	6.4000	28.0000	2186.0000	298.0000	4.2600	5.0000
0.6100	1.0000	4.8000	27.0000	2122.0000	184.0000	7.1300	3.2000
1.0000	1.0000	7.4000	26.0000	2111.0000	165.0000	3.2400	2.9400
0.7600	1.0000	6.0000	27.0000	2120.0000	177.0000	6.5000	3.0800
0.6350	1.0000	5.4000	28.0000	2187.0000	300.0000	7.3600	5.2500
0.5100	1.0000	6.9000	27.0000	2175.0000	280.0000	6.8000	4.9100
0.5600	1.0000	5.5000	28.0000	2152.0000	225.0000	3.1600	4.0100
0.6600	1.0000	6.3000	25.9000	2175.0000	202.0000	3.5400	3.6000
0.5600	1.0000	5.8000	23.9000	2133.0000	212.0000	4.7800	3.9000

3.1 Modelling and Optimization

In this study, an attempt is made to develop a second order mathematical relationship between selected input variables, using response surface methodology (RSM). The target of the optimization model was to maximize compressive strength

3.2 Model Development

For the development of the models certain statical 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.The sequential sum of square was also determined for the compressive strength parameter which is presented in table 2

Table 2: Sequential sum of square for compressive strength

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob > F	
Mean vs Total	268.4200	1	268.4200			
Linear vs Mean	1.1900	3	0.4000	0.5900	0.6301	
2FI vs Linear	0.8200	3	0.2700	0.3600	0.7828	
Quadratic vs 2FI	0.3300	3	0.1100	0.1100	< 0.0001	Suggested
Cubic vs Quadratic	3.9000	4	0.9700	1.0300	0.4635	Aliased
Residual	5.6800	6	0.9500			
Total	280.3400	20	14.0200			

The lack of fit test was conducted for the compressive strength which suggested the quadratic model as presented in table 3

Table 3: Lack of fit test for compressive strength

	Sum of		Mean	F	p-value	
Source	Squares	Df	Square	Value	Prob > F	
Linear	6.5400	11	0.5900	0.7100	0.7063	
2FI	5.7100	8	0.7100	0.8500	0.6011	
Quadratic	5.3800	5	1.0800	1.2800	0.3954	Suggested
Cubic	1.4900	1	1.4900	1.7700	0.2405	Aliased
Pure Error	4.1900	5	0.8400			

To check for the significance of the quadratic model one-way analysis of variance (ANOVA) table was generated for the compressive strength model which is presented in Table 4

Table 4: ANOVA table for compressive strength

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**Df**	**Square**	**Value**	**Prob > F**	
Model	2.3400	9	0.26	0.27	< 0.0001	significant
A-water	1.648E-003	1	1.648E-003	1.720E-003	0.9677	
B-cement	0.6700	1	0.6700	0.7000	0.4219	
C-sand	0.5100	1	0.5100	0.5400	0.4804	
AB	0.1700	1	0.1700	0.1700	0.6866	
AC	0.6300	1	0.6300	0.6600	0.4353	
BC	0.0250	1	0.0250	0.0260	0.8741	
A^2	0.1000	1	0.1000	0.1000	0.7529	
B^2	0.2200	1	0.2200	0.2300	0.6454	
C^2	0.0160	1	0.0160	0.0170	0.9000	
Residual	9.5800	10	0.9600			
Lack of Fit	5.3800	5	1.0800	1.2800	0.3954	not significant
Pure Error	4.1900	5	0.8400			
Cor Total	11.9200	19				

To validate the adequacy of the quadratic model the goodness of fit statistics for compressive strength of the block presented in Table 5

Table 5: GOF statistics for compressive strength

Std. Dev.	0.9800	R-Squared	0.9000
Mean	3.6600	Adj R-Squared	0.8500
C.V. %	26.7200	Pred R-Squared	0.7300
PRESS	46.8700	Adeq Precision	11.6860

The optimal equation which shows the individual effects and combine interactions of the selected input variables against the mesured compressive strength is presented based on the actual values in Equation 2
Final Equation in Terms of Actual Factors:

$$Y_{cs} = 4.24790 - 0.94056A + 0.034781B - 0.060779C + 0.89844AB + 0.17578AC - 0.035156BC - 0.52144A^2 - 0.76451B^2 + 2.07765E\text{-}003C^2 \quad (2)$$

The normal probability plot of residual for the compressive strength of the block is presented in Figure 1

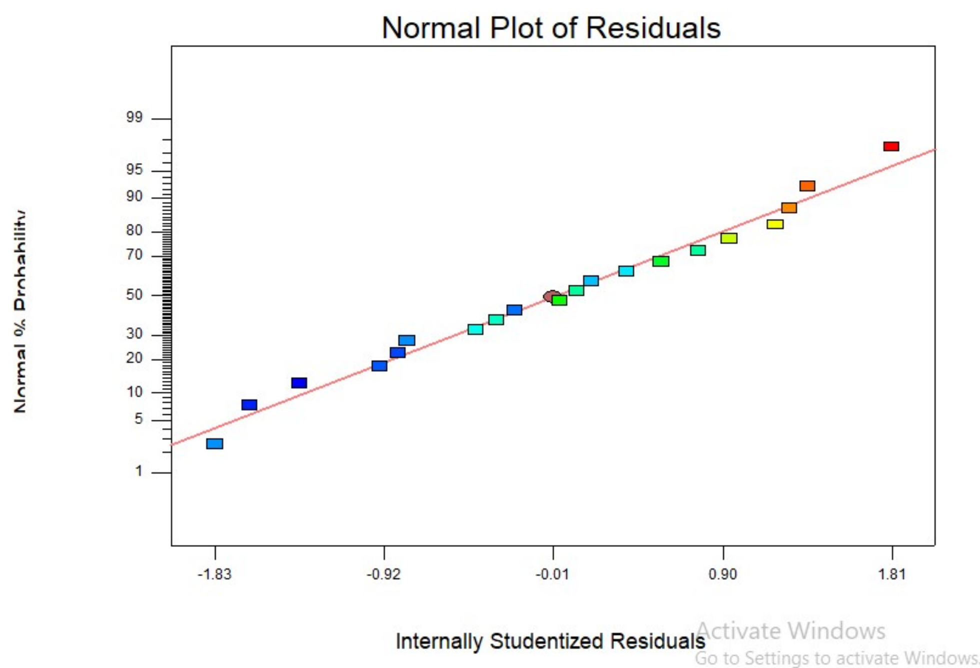

Figure 1: Normal probability plot of studentized residuals for compressive strength

To study the effects of water and cement on the compressive strength of the block a surface plot is produced as shown in figure 2

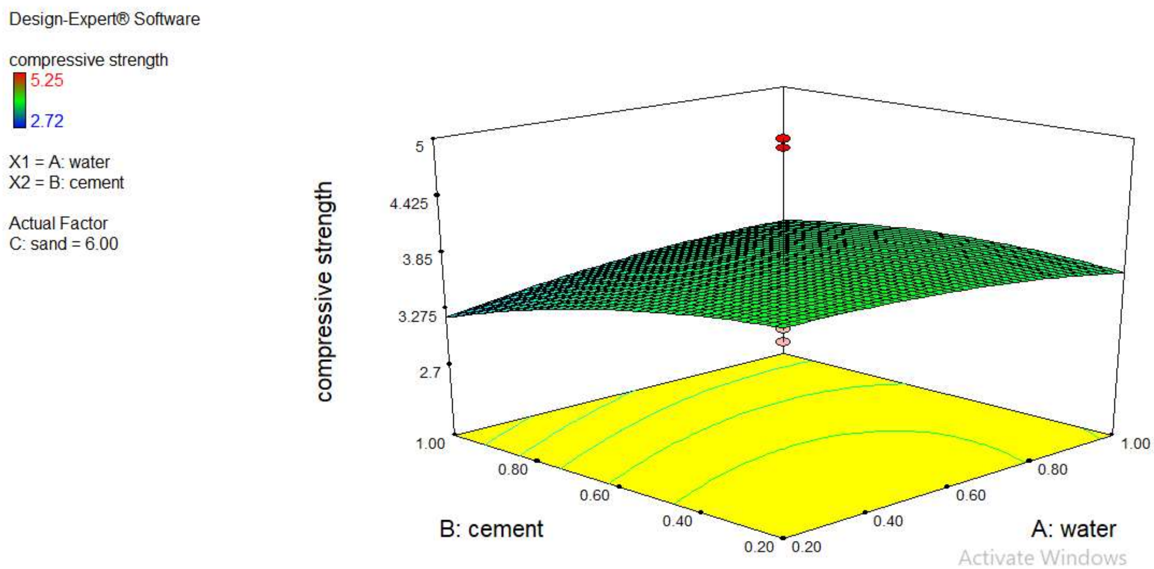

Figure 2: Effect of Cement-Water Ratio on the Compressive Strength

To study the effects of water and sand on the compressive strength of the block a surface plot is produced as shown in figure 3

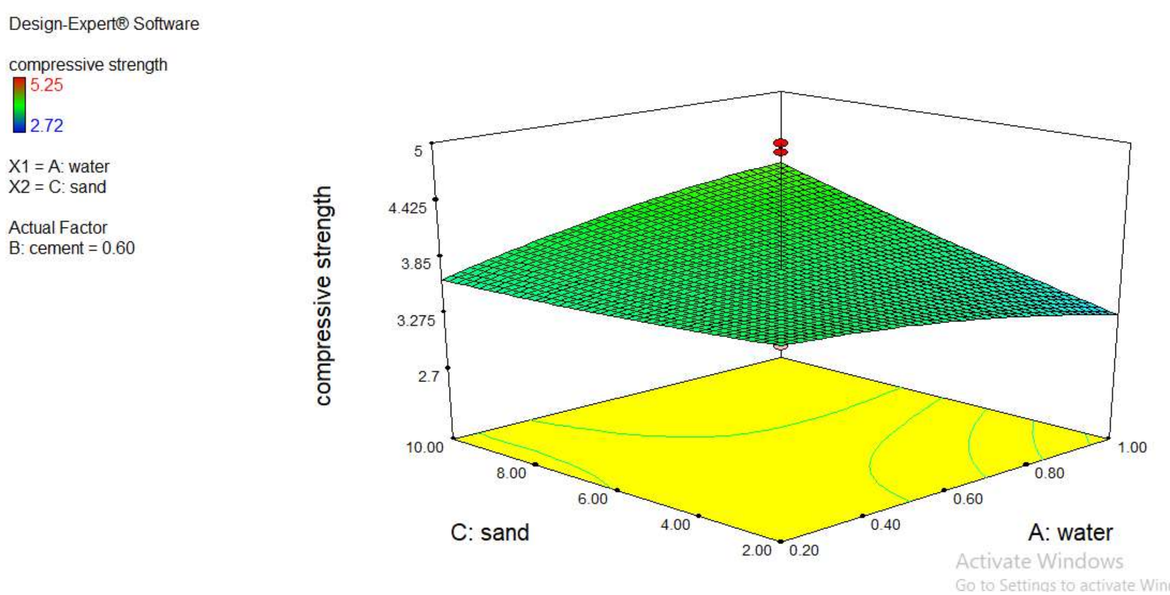

Figure 3: Effect of Sand-Water Ratio on the Compressive Strength

To study the effects of cementr and sand on the compressive strength of the block a surface plot is produced as shown in figure 4

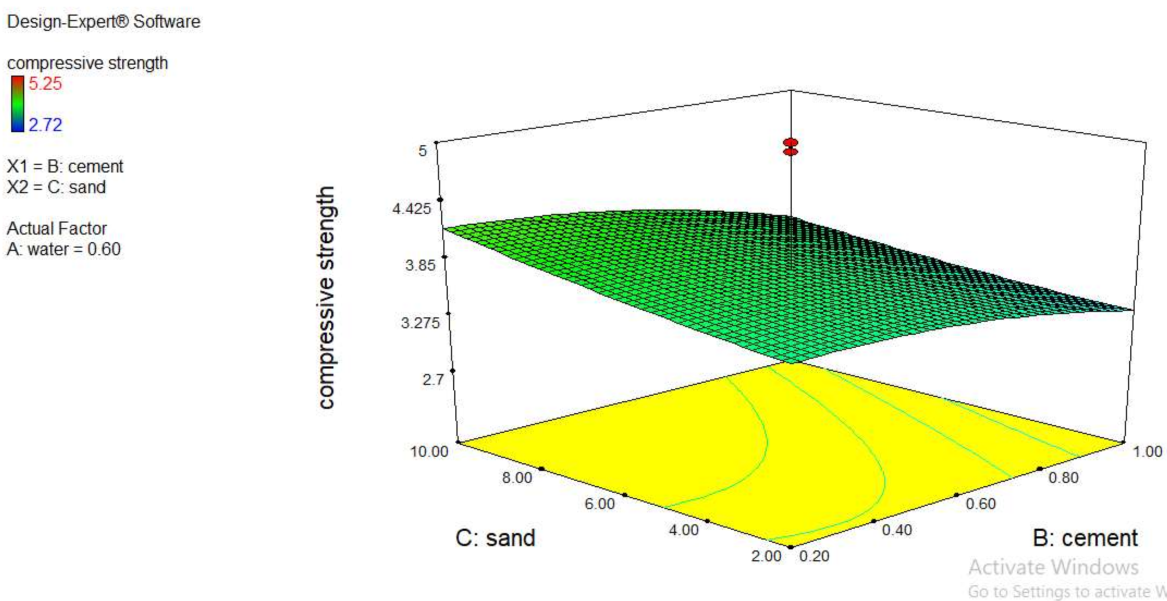

Figure 4: Effect of Sand-Cement Ratio on the Compressive Strength

The numerical solution has obtained and presented in table 6

Table 6: The Numerical Optimal Solutions

water	cement	Sand	Mass	Density	Failure load	Compressive strength	Water absorption	Desirability
0.56	0.42	10.00	27.3287	2149.19	234.861	4.08817	6.60831	0.949
0.57	0.42	10.00	27.3352	2149.24	235.116	4.09196	6.6168	0.849
0.57	0.41	10.00	27.3395	2149.29	235.207	4.09294	6.62778	0.749
0.57	0.42	10.00	27.3388	2149.24	235.327	4.0954	6.61344	0.649
0.59	0.43	10.00	27.3387	2149.18	235.608	4.1013	6.589	0.449
0.52	0.40	10.00	27.3179	2149.29	233.686	4.06832	6.63182	0.449
0.49	0.41	10.00	27.2952	2149.23	232.408	4.04877	6.61518	0.449
0.65	0.45	10.00	27.3665	2149.36	236.975	4.12581	6.56076	0.448
0.44	0.41	10.00	27.2497	2149.16	229.665	4.00708	6.58172	0.447
0.46	0.46	10.00	27.2122	2148.41	229.138	3.99957	6.50576	0.447

4. Conclusion

The study has analyzed the process parameters considered in the manufacture of sandcrete blocks. This sand type used in this study is sand collected from Okhuare in Edo state. The sand samples was collected and block samples were produced using appropriate design of experiment considering the ratio of water, sand and cement as the input process parameters, while the output parameter is the compressive strength. The experiment was scientifically performed and the results accurately measured and a mathematical model that can adequately explain the effects of the process parameters on the compressive strength of the sandcrete block was developed and the most significant factor influencing the strength and durability of the block was identified and statistically justified. This study selected the quadratic model as the most suitable model for this study.

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