Heliyon 6 (2020) e04276

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Process parameters optimization for eco-friendly high strength sandcrete block using Taguchi method

Chijioke Christopher Ikeagwuani, Donald Chimobi Nwonu *, Chiagoziem Kanayo Ugwu, Chukwudi Cajethan Agu

Civil Engineering Department, University of Nigeria, Nsukka, Enugu State, Nigeria

ARTICLE INFO

Keywords:
Civil engineering
Construction engineering
Concrete technology
Cement additive
Cement
Bulk density
Compressive strength
Optimization
Sandcrete blocks
Taguchi approach
Water absorption

ABSTRACT

The need for developing sustainable cement-based materials is crucial for the prevention of environmental degradation and promotion of sustainable technologies. In the present study, a sustainable cement-based material was developed for sandcrete block production using coconut shell ash (CSA). The product development was executed using the Taguchi robust design approach, in which an L18 mixed level orthogonal array was adopted. The process parameters investigated were the end-web to center-web (E/C) ratio of the sandcrete block, water-cement (W/C) ratio and CSA content. The evaluated responses include the compressive strength (CS), bulk density (BD) and water absorption (WA). The result obtained showed that for the CS, all the process parameters had a statistically significant effect at 0.05 alpha level, while only the W/C ratio had a statistically significant effect on the BD and WA. The optimal settings of the process parameters for CS and BD were obtained at E/C ratio of 1:2, W/C ratio of 0.65 and CSA content of 5% while that for WA was obtained at E/C ratio of 1:1, W/C ratio of 0.65 and CSA content of 20%. The developed sandcrete blocks are suitable for load-bearing masonry units and areas with moisture exposure.

1. Introduction

[1]The soaring cost of Portland cement, an essential construction material that is used principally as binder in cement-based construction, has necessitated the need to find replacement for it either partially or wholly. 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 [1, 2, 3, 4, 5, 6, 7, 8]. Several potential low cost materials such as bone powder ash [9], granite sludge [10], ceramic waste powder [11], cement kiln dust [1], slag waste [12], and others [13, 14, 15, 16, 17, 18]which are otherwise considered as waste materials have been recycled and used as partial replacement of cement in eco-friendly and low cost cement-based construction.

Numerous eco-friendly and low cost cement-based construction products abound in practice. One of such products is sandcrete block, which is a composite material produced from a mixture of Portland cement, water and fine aggregate in the absence of coarse aggregate. Sandcrete blocks are utilized mainly in West African countries particularly Ghana and Nigeria as walling unit because of its alluring and beneficial properties, which include low shrinkage, high CS, high density and low thermal conductivity [19, 20, 21, 22, 23]. Transmission of structural loads from overlaying structural elements to the foundation for stability is done frequently using sandcrete blocks. However, sandcrete block properties are adversely affected by some factors. Inadequate water content, poor haulage and storage, improper molding, poor mixing of constituent materials, inadequate curing and poor quality of constituent materials as well as poor batching of aggregates are some of the prominent factors identified by Baiden and Tuuli [23] and Uzoamaka [24] that affect sandcrete block properties negatively. Lately, several methods have been adopted or recommended to improve the quality of sandcrete blocks produced.

Kolovos et al. [25], investigated the physical and mechanical properties of sandcrete blocks produced by partial replacement of cement with metakaolin. The results obtained showed considerable improvement in the properties of the produced sandcrete blocks when there was increase in percentage of metakaolin. The metakaolin was added by

* Corresponding author.
E-mail address: donald.nwonu@unn.edu.ng (D.C. Nwonu).

[1] Bulk density (BD) Coconut shell ash (CSA), compressive strength (CS), end-web to center-web (E/C), signal-to-noise (S/N), water absorption (WA), water-cement (W/C), Portland limestone cement (PLC), calcium silicate hydrate (CSH), calcium aluminum hydrate (CAH).

https://doi.org/10.1016/j.heliyon.2020.e04276
Received 7 April 2020; Received in revised form 20 May 2020; Accepted 18 June 2020

weight of the cement. Similarly, Omoregie [26] studied the CS of hollow sandcrete blocks and cubes modified with steel chips. The steel chips were added from 1% up to 15%, and the CS was determined after 7, 14 and 28 curing days. The results obtained show that at all curing age, the CS gradually increased to attain peak values at 4% steel chip inclusion, after which the strength rapidly declined. The optimally developed hollow sandcrete block with 4% steel chips was found to be suitable as both load bearing and non-load bearing internal masonry units. Ikeagwuani et al. [27] evaluated the strength properties of two sets of sandcrete blocks whose cement contents were replaced partially with an agro-based material, CSA. The first sets of sandcrete blocks were produced with E/C ratio of 1:1 while the second sets of sandcrete blocks were manufactured with E/C ratio of 1:2. Significant improvement in the sandcrete blocks strength properties (CS, WA, sorptivity and BD) determined were observed at 10% replacement of the cement with CSA for both the first and second sets of sandcrete blocks.

Mohammed and Cheeseman [22] utilized an industrial waste, oil drill cuttings, which are fine fragments of shale and sandstone, to improve the properties of sandcrete blocks in their study. The results obtained from the sandcrete blocks produced with the waste oil drill cuttings treated with thermal desorption showed significant improvement in the properties evaluated. An increase in density of the sandcrete blocks and reduction in the sorptivity, WA and thermal conductivity was observed when 50% weight of sand was replaced with the treated oil drill cuttings. Akinyele and Toriola [28] studied the effect of crushed plastics on sandcrete block properties and noted that optimal CS was observed in sandcrete blocks which contained 5% crushed plastics used to partially replace fine aggregate.

Cassava peel ash was utilized in the study by Amartey et al. [29] for the partial replacement of cement in sandcrete block production. The blocks were prepared at up to 30% additive replacement, considering various W/C ratios (0.45, 0.5, 0.55 and 0.60). The result obtained showed that the CS general decreased with increase in both the additive content and the W/C ratio. Okpala [30] adopted rice husk ash as a cement blended admixture in the production of sandcrete blocks. Various percentage replacements were used including 30%, 40%, 45%, 50% and 60%. At 30% replacement, after 90 days curing period, the CS was found to decline by about 28% and 33% for respective cement to sand ratios of 1:8 and 1:6. Further drop in CS was observed at higher percentage replacements. In a related study, sawdust ash was used to complement cement in hollow sandcrete block manufacture [31]. Different percentages of sawdust ash, ranging from 5% to 25% with four intervals and varying curing ages (3, 7, 14, 21, 28 and 56 days) were studied. The result obtained clearly showed that the use of sawdust ash caused a significant reduction in CS. Furthermore, the CS continuously increased with increase in curing time for all percentage replacements. At 56 days curing, reduction as much as 33% was observed for 25% replacement in comparison with the control.

Despite the improvement in the properties of sandcrete blocks produced after the inclusion of economical additives to it, there appears to be a seeming lack of interest among researchers in incorporating mathematical models to optimize the constituents of sandcrete blocks in other to achieve optimal results in its properties. It is against this backdrop that this study seeks to integrate Taguchi method, an optimization technique to enhance the properties of sandcrete blocks used in practice. An industrial waste, CSA was included into the design and production of sandcrete blocks. This was used to replace cement partially and also to act as binder in the mixture in other to achieve a low-cost hollow sandcrete blocks production.

1.1. Taguchi method

Taguchi method for the optimization of process parameters is an effective tool that is being utilized in most industries since its introduction in the design of experiments. Taguchi approach is an off-line quality control technique done to improve the manufacturability and reliability of a product as well as to cause a reduction in its lifetime cost and product development. Prior to the introduction of Taguchi method, manufacturers of most products use off-line quality control methodology which are less developed than the one proposed by Taguchi. In addition, they were not extensively used in on-line quality control. The off-line quality control methods utilized by most product manufacturers include sensitivity analysis, prototype tests, reliability studies, design reviews and accelerated life tests [32].

Taguchi adopted a three-stage approach or fundamental principles in his off-line quality control method for process optimization. The three-stage approach for the optimization of an engineering system proposed by Taguchi includes system design, parameter design and tolerance design [33, 34, 35, 36]. In addition to the three-stage approach, Taguchi method also uses two essential tools for the optimization of process parameters and they include special matrices of matrix experiments known as orthogonal arrays that enables parameters effect to be evaluated efficiently and the S/N ratios.

The S/N ratio is used for the interpretation of experimental factors and optimization of performance. It signifies the ratio between signal power to that of noise power. The S/N ratio term is used frequently in the field of communication and electrical engineering where it is highly desirable to maximize an amplifier output whilst reducing its noise level to the barest minimum. Performance variability or deviation of the selected parameters when noises are present is determined using the S/N ratio function. Higher deviation from the target or ideal value implies a higher loss in quality [37].

Typically, product development using the Taguchi method often requires the execution of a sequence of objectives after obtaining results of the experimental design [32, 38]. The first involves the identification of the best level setting of the process parameters, which is executed by computing the level averages. The second step requires the determination of the contribution of each factor to the variation of the responses through analysis of variance. This is usually useful in tolerance design so as to tighten the range of the significant factors in subsequent experiments. Finally, the optimum value of the responses is computed using the best level setting of the process parameters by applying the additive formula.

The Taguchi method has been applied in various engineering applications for product development. Kurt et al. [39] applied the Taguchi method for optimizing the process parameters in dry drilling processes. The responses optimized were the surface finish and hole diameter accuracy. The result show that minimum diametral error was obtained using a drilling depth of 15 mm, feed rate of 0.15 mm/rev, cutting speed of 30 m/min and HSS drilling tool. On the other hand, optimal surface finish was achieved using a feed rate of 0.15 mm/rev, cutting speed of 30 m/min and HSS drilling tool. Kumar and Singh [40]optimized the turning parameters of the dry turning process. These parameters include tool nose radius, cutting speed, feed rate and depth of cut, in which the optimum responses were respectively obtained at 0.4 mm, 78.88 m/min, 0.05 mm/min and 0.4 mm. Taguchi method was utilized in the optimization of CS of ternary blended self-compacting mortar by Teimortashlu et al. [41]. The process parameters involved included fly ash content, slag content and nano silica content. The results of the study indicated that the fly ash content contributed most to the CS, followed by the nano silica and then the slag. An optimum CS of 38.5 MPa was gotten using 20% fly ash, 20% slag and 4% nano silica in comparison with 28.56% of the control. Several other applications of the Taguchi method have been reported in several literatures [42, 43, 44, 45, 46, 47].

2. Materials and method

2.1. Materials

Fine aggregate (sand) utilized in this study was collected from a sand deposit located at Akachele hill, Obimo (L 6°49′36″N, L7°19′15″E), Enugu state situated in the eastern part of Nigeria. The sand deposit

Table 1. Physical properties of fine aggregate.

S/N	Properties	Values
1	Specific gravity	2.61
2	Water absorption, %	2.52
3	Fine materials, % (<75μm)	2%
4	Fineness modulus	2.76

where the aggregate was obtained can be classified as pit sand. Other classifications of sand include river sand, crushed stone sand and sea sand [21]. Table 1 shows the physical properties of the sand used in this study while its particle size distribution (PSD) curve is shown in Figure 1. The PSD of the sand was performed in accordance with BS 812 [48]. As illustrated in Figure 1, the PSD curve of the sand falls within the stipulated band limit of the NIS 978 code [49]. Furthermore, the natural moisture content of the fine aggregate was 2.52% while its specific gravity was 2.61.

The PLC, which was used as the binder in the sandcrete mixture, was obtained commercially from Nsukka, Enugu state, Nigeria. The cement grade was 42.5R and it met the requirements of NIS 444-1 [50]. The chemical composition of the PLC, which is also described as CEM II by NIS 444-1 [50], is illustrated in Table 2. The specific gravity conducted in accordance with BS 812 [48] on the PLC gave a value of 3.15 while the initial and final setting times of the cement gave values of 116mins and 302mins respectively. These values (initial and final setting times) are within acceptable limit as pointed out by Joel and Mbapund [51].

Portable water was used in the production of the sandcrete blocks in this study. The portable water was free from harmful acid, alkalis and organic materials. Baiden and Asante [21] noted that the water to be used for the production of sandcrete blocks should equally be fit for drinking and that the dissolved solid present in it should not exceed 200 parts per million. The pH value should range from 6.0 to 8.0.

Table 2. Chemical composition of materials.

Element oxide	PLC (%)	CSA (%)
Silica (SiO_2)	10.31	43.5
Iron oxide (Fe_2O_3)	6.22	12.6
Alumina (Al_2O_3)	2.41	15.2
Phosphorous oxide (P_2O_5)	-	0.4
Soda (Na_2O)	0.001	0.47
Potash (K_2O)	-	8.49
Lime (CaO)	78.35	3.25
Magnesia (MgO)	0.003	5.01
Titanium oxide (TiO_2)	0.3	-
Magnesium oxide (MnO)	0.06	0.19
SO_3	0.9	-
CuO	0.02	-
ZnO	-	0.5
SrO	0.03	-
ZrO_2	0.004	-
Co_3O_4	0.004	-
HgO	0.12	-
Loss on ignition	1.268	10.39

Coconut shell that was used for the production of CSA, one of the process parameters to be optimized, was sourced locally from Nsukka. It is a 5–10 mm thick fibrous outer layer of coconut shell [52, 53]. Table 2 shows the chemical composition of the CSA used in this study. The result shows that CSA is pozzolanic and can be classified as class F with sum of SiO_2, Al_2O_3 and Fe_2O_3 above 70% and SO_3 less than 5% [54].

2.2. Production of coconut shell ash

The procedure for the production of the CSA employed in this study is similar to the method described by Ikeagwuani et al. [27] but with slight

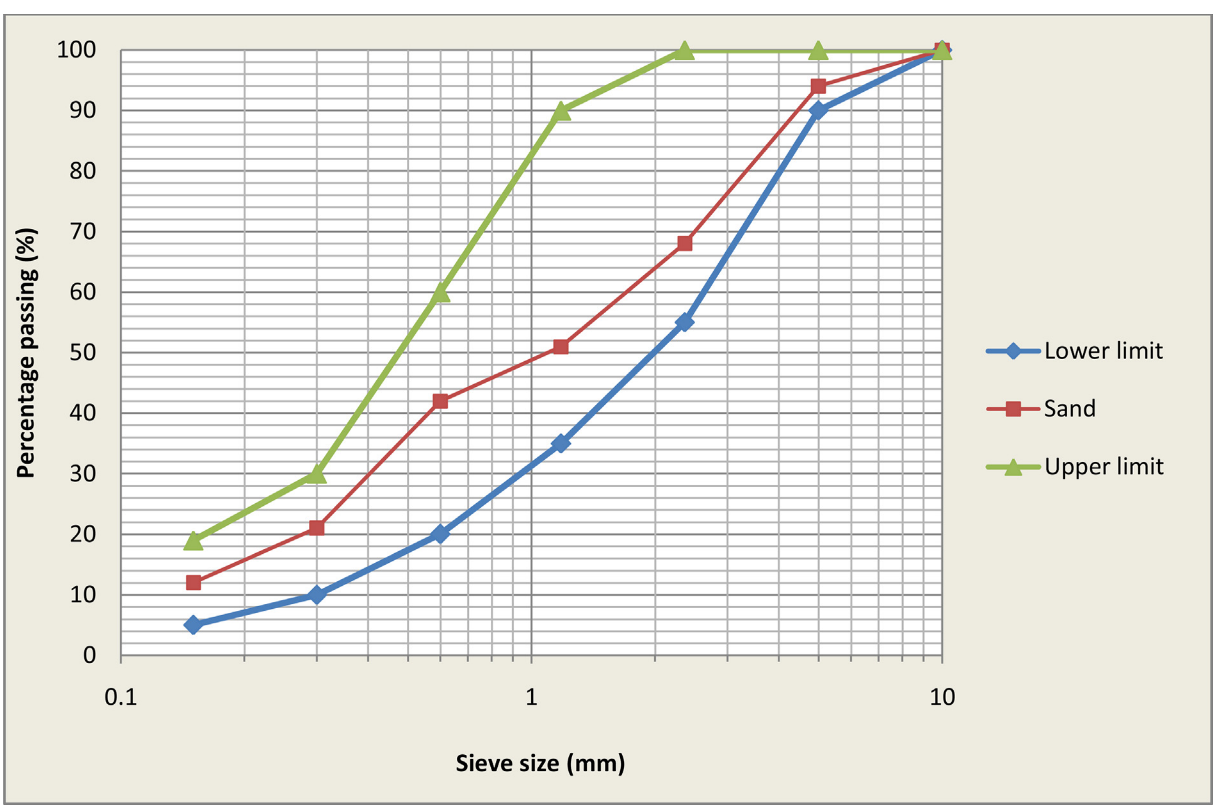

Figure 1. Particle size distribution curve of sand.

Figure 2. Burnt coconut shell.

Table 3. Process parameters with their various levels.

S/N	Process parameters	Level		
		1	2	3
1	E/C ratio	1:2	1:1	-
2	W/C ratio	0.55	0.60	0.65
3	CSA	5	10	15

modification. The method involves two stages, which are the preparation and carbonization stages. In the preparation stage, the coconut shells used for the production of the CSA were sun-dried for a duration of one week after collection. After drying, the coconut shells were broken down into smaller fragments with the aid of a hammer and then poured into a large tray where it was allowed to dry further under the sun for three days, to remove any entrapped moisture. In the carbonization stage, the sun-dried coconut shells were transferred into the furnace and incinerated at a temperature of 400 °C in accordance with the procedure described by Amarnath [55]. Shortly after burning, the coconut shells were removed from the furnace and made to cool rapidly in less than an hour by sprinkling little amount of water on it (Figure 2). This was done in other to prevent the burnt coconut shell from turning into ash suddenly thereby reducing the amount of the ash produced. The burnt and later cooled coconut shells were crushed in a crushing machine where it was reduced into powdery form. The crushed coconut shell ash was then made to pass through Bs. No 200 test sieve and packaged in air-tight container prior to usage.

2.3. *Optimization with Taguchi method*

As noted earlier, Taguchi approach uses two essential tools for the optimization of process parameters and they include the S/N ratios and special matrices of matrix experiments known as orthogonal arrays that enables parameters effect to be evaluated efficiently and also allows data to be analyzed easily.

2.3.1. *Orthogonal array selection for sandcrete block production*

In the generation of the orthogonal arrays, Taguchi mixed level L18 (6̂1 x 3̂2) orthogonal array was chosen. This is because it is the minimum array which can achieve a balanced design for the mixed level factors considered in the present study. The process parameters, which are the controllable factors to be optimized, include W/C ratio, CSA content and E/C ratio of the mold used for the production of sandcrete blocks. For the assignment of levels to the process parameters, the E/C ratio was assigned two levels while the W/C ratio and the CSA were assigned three levels each as shown in Table 3. Two levels were used for the E/C ratio because it is required to investigate the improvement in sandcrete block properties due to a new mold design, which was compared with the conventionally used mold [27]; hence, the two levels. For the CSA and W/C ratio, a previous study suggested optimal performance for CSA of 10% and W/C ratio of 0.60 [27]. Hence, the present study sought to tighten the range close to those values by selecting one level above and below the aforementioned optimum from previous study; hence, the three levels investigated. The design of the orthogonal array was done such that a balanced design was achieved by ensuring that for each level of any factor, all other levels of that factor was represented equal number of times [56]. Each row of the orthogonal array corresponds to the number of experiments to be conducted. The orthogonal array generated for the production of the sandcrete blocks is presented in Table 4.

2.3.2. *Signal-to-noise ratio*

Signal-to-noise ratio used for optimization in Taguchi method was designed such that the desirable positive value can be obtained and it depends on the quality characteristics criteria [57]. The quality characteristic is described as an appealing outcome that is not unconnected with evaluations and estimated values plus the units of measure [38]. There are three variants of quality characteristics being measured by the S/N ratio formula and they are smaller-is-better (Equation 1) which can be used to minimize the response; larger-is-better function (Equation 2) which maximizes the responses; and nominal-is-best function (Equation 3) which normalizes the responses [58]. In this study, SIB function was employed to optimize the WA while BD and CS were optimized using the LIB function.

$$\eta = -10log_{10}\left(\frac{1}{w}\sum_{q=1}^{w} y_q^2\right) \tag{1}$$

$$\eta = -10log_{10}\left(\frac{1}{w}\sum_{q=1}^{w} \frac{1}{y_q^2}\right) \tag{2}$$

Table 4. Layout of the orthogonal array.

S/N	Actual values			Coded values		
	E/C ratio	W/C (%)	CSA	A	B	C
1	1:2	0.55	5	1	1	1
2	1:2	0.55	10	1	1	2
3	1:2	0.55	20	1	1	3
4	1:2	0.60	5	1	2	1
5	1:2	0.60	10	1	2	2
6	1:2	0.60	20	1	2	3
7	1:2	0.65	5	1	3	1
8	1:2	0.65	10	1	3	2
9	1:2	0.65	20	1	3	3
10	1:1	0.55	5	2	1	1
11	1:1	0.55	10	2	1	2
12	1:1	0.55	20	2	1	3
13	1:1	0.60	5	2	2	1
14	1:1	0.60	10	2	2	2
15	1:1	0.60	20	2	2	3
16	1:1	0.65	5	2	3	1
17	1:1	0.65	10	2	3	2
18	1:1	0.65	20	2	3	3

$$\eta = 10 log \frac{S_y^2}{\bar{y}_q} \tag{3}$$

where,

η signifies the S/N ratio

w represents the number of the response replicates

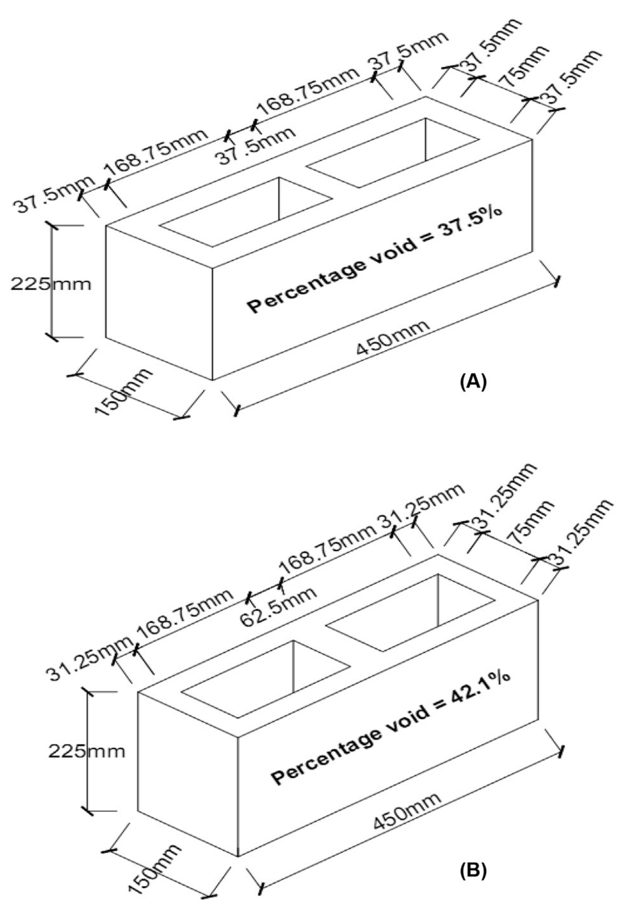

Figure 3. Schematic diagram of the moulds: (A) mould with end-web to centre-web ratio of 1:1; (B) mould with end-web to centre-web ratio of 1:2.

y_q signifies the responses of the replicated experiments for each test run

$\bar{y}_q$ represents the average response of the experimental replications

S_y^2 is the series sample variance

2.3.3. Effect of parameter on responses

Every parameter effect on the responses was evaluated. . This was achieved by setting a particular parameter to a certain level, obtaining the mean of all the responses of every experiments in which that parameter was set to that level and then subtracting the overall mean of the responses from it. Eq. (4) was applied to determine each parameter effect on the responses.

$$P_d = \frac{1}{n}\sum_{j=1}^{n} y_j - \bar{y}_o \tag{4}$$

P_d represents the effect of parameter P on level d, and n is the number of experiments

2.3.4. Analysis of variance (ANOVA)

A thorough statistical approach useful for quantifying the effect of process parameters on the responses is the ANOVA. The ANOVA considers the relative variations of the responses, as well as the mean values from the target values, considering the S/N ratio function [32, 56]. This procedure was used to analyze the results in order to quantify the relative contributions of the factors to the changes in the responses. It was also used to identify factors which had a statistically significant effect on the responses. This is executed by computing the sum of squares (SS), mean squares (V), variance ratio (F-ratio), percentage contribution (P) and tail probability (p-values), considering the degrees of freedom (DOF) of each process parameter [32, 56].

2.3.5. Prediction of responses

The optimized responses can be predicted once each parameter effect on the responses, the overall mean and the S/N ratios have been calculated. The governing equation utilized for the prediction of the responses is expressed mathematically as shown in Eq. (5):

$$Y_{pred} = \overline{k_o} + \sum P_e + \sum I_e + \varepsilon \tag{5}$$

Figure 4. Fabricated moulds: (a) mould with end-web to centre-web ratio of 1:1; (b) mould with end-web to centre-web ratio of 1:2.

where

$\overline{k_o}$ represents the overall mean of the responses or overall mean of the S/N

P_e represents the parameter effects on the responses

I_e signifies the interaction effect of the responses

ε represents the statistical error

In the Taguchi method adopted for the present study, statistical error or interaction of parameters were not considered during its formulation. Therefore Eq. (5) is reduced to:

$$Y_{pred} = \overline{k_o} + \sum P_e \tag{6}$$

2.4. Production of sandcrete blocks

The nominal dimension of the molds (450 × 225 × 150mm) utilized for the sandcrete blocks production was in accordance with NIS 978 [49]. Figure 3 shows the schematic diagram of the molds while Figure 4 displays the molds used in the study. The molds are similar to the ones utilized by Ikeagwuani et al. [27] in their study on the improvement of sandcrete blocks with coconut shell ash. In this present study, the sandcrete blocks were produced using a sand/binder ratio of 6:0 [59]. The constituent materials for the sandcrete blocks were manually and thoroughly mixed to obtain a homogenous mixture. This ensures that sandcrete blocks of good quality were produced [23]. After mixing the materials thoroughly, it was transferred gently into the mold that was placed on a flat wooden pallet and compacted by employing hand ramming compaction method. The hand ramming compaction method is one of the three types of compaction methods that can be employed for the compaction of the mixture in the mold [21].

Other methods include manual tamping machine and the motorized vibration method. The hand ramming compaction method has the advantage that it is relatively inexpensive and it gives a higher CS than the manual tamping machine method as well as being commonly used on site for the production of sandcrete blocks [21]. Shortly after compaction, the freshly prepared sandcrete blocks were de-molded. The produced sandcrete blocks were cured for 28 days to allow for the development of sufficient strength of the blocks. Curing was done by sprinkling water on the manufactured blocks twice daily (morning and evening) and then covering with damp sacks in other to prevent loss of moisture and to allow for sufficient hydration of the binder. All the tests conducted on the sandcrete hollow blocks were performed in triplicate. Figure 5 shows the produced sandcrete hollow blocks.

This study utilized the NIS 978 [49] to perform the experimental tests. The NIS 978 [49] standard was used because most international standards, to the extent of the authors' knowledge, did not make adequate provision for testing of hardened sandcrete blocks. The explanation for this inadequate provision can be adduced to the limited applicability of sandcrete blocks in most parts of the world. As remarked earlier, sandcrete blocks are used predominantly in West African countries particularly Nigeria, Ghana and Senegal.

Furthermore, most international standard testing schemes are dedicated largely to the testing of hardened concrete blocks or bricks which does not account for the peculiarities associated with the sandcrete blocks. For instance, BS EN 12390, Part 3 [60], which deals with the testing of hardened concrete, specifies that during the application of load to the hardened concrete blocks, that constant loading rate should be $5 \mp 0.5N/mm^2.s$ for concrete blocks with CS less than or equal to $7N/mm^2$, and $10 \mp 0.5N/mm^2.s$ for concrete blocks with CS greater than $7N/mm^2$. These constant loading rates specified in the BS EN 12390, Part 3 [60] are high and cannot be favorably utilized for the testing of hardened sandcrete blocks. The NIS 978 [49] code, unlike the BS EN 12390, Part 3 [60] specifies a much lower constant loading rate to account for any low CS that may develop during the testing of the hardened sandcrete block.

Figure 5. Freshly prepared hollow sandcrete blocks.

Table 5. Summary of laboratory results performed with the Taguchi designed experiment.

S/N	Process parameter			CS (N/mm^2)	S/N ratio (dB)	BD (kg/m^3)	S/N ratio (dB)	WA (%)	S/N ratio (dB)
	A	B	C						
1	1	1	1	3.56	10.98	2025.24	66.1223	14.4	23.21
2	1	1	2	3.26	10.21	1945.60	65.7720	14.7	23.38
3	1	1	3	2.96	9.42	1884.92	65.5045	15.9	24.05
4	1	2	1	3.63	11.19	2017.66	66.0966	11.5	21.19
5	1	2	2	3.48	10.82	1881.13	65.4876	15.7	23.72
6	1	2	3	3.56	10.98	1934.22	65.7301	14.0	22.72
7	1	3	1	4.07	12.19	2093.51	66.4165	13.0	22.70
8	1	3	2	4.00	12.01	1964.56	65.8649	14.3	23.13
9	1	3	3	3.56	10.98	2059.38	66.2745	10.0	19.72
10	2	1	1	3.41	10.64	1938.44	65.7480	13.0	21.83
11	2	1	2	2.96	9.42	1917.37	65.6541	13.0	22.06
12	2	1	3	2.74	8.74	1797.97	65.0904	16.0	24.08
13	2	2	1	3.48	10.75	1875.23	65.4603	14.3	23.13
14	2	2	2	2.81	8.97	1994.62	65.9952	11.3	21.14
15	2	2	3	2.74	8.74	2019.20	66.1035	11.3	21.09
16	2	3	1	3.33	10.42	2005.16	66.0357	11.0	20.85
17	2	3	2	3.93	11.87	2036.76	66.1768	10.3	19.41
18	2	3	3	3.56	10.98	1994.62	65.9808	10.1	20.03

In addition, the specification for the test sizes and shapes of the blocks to be molded are not similar in both the BS EN 12390 Part 1 [61] and NIS 978 [49] codes, therefore subjecting them to similar tests may not be appropriate. Lastly, in the determination of WA of the hardened blocks, the NIS 978 [49] standard specified that the blocks should be immersed completely in water for 24 h whereas the BS 1881, Part 122 [62] stipulates that the hardened concrete should be immersed in water for 30 ∓ 0.5 min. The NIS 978 [49] standard, in terms of WA test, is more robust because it simulates the worst possible condition the hardened sandcrete blocks will be exposed to in practice.

2.5. Experimental procedure

The experimental procedure adopted in this study was carried out based on the guidelines stated in the NIS 978 [49] standard. The test performed on the hardened sandcrete blocks include CS, BD and WA as recommended in the NIS 978 [49] standard.

2.5.1. Compressive strength

Compressive strength test was conducted in accordance with NIS 978 [49]. The test was carried out by subjecting the samples to axial loads from compression machine until failure occurred. The load was applied at strain rate of $5N/mm^2$ per minute. The CS test for each experimental run was conducted in triplicate.

2.5.2. Bulk density

Bulk density of sandcrete hollow blocks is an indication of how well the constituent materials are closely packed together within the sandcrete blocks. The procedure described by NIS 978 [49] was used for the determination of the BD of the sandcrete hollow blocks in this study. Samples were dried to a constant mass at a temperature of 110 °C in an oven, cooled at room temperature (27 °C $\mp$ 2 °C) and weighed to the nearest kilogram. Subsequently, the volumes of the sandcrete blocks were determined and the bulk densities calculated thereafter. The BD was determined in triplicate and the average value reported.

2.5.3. Water absorption

Water absorption of the hollow sandcrete blocks was done in accordance with NIS 978 [49]. Samples were dried in an oven to a constant mass, cooled at room temperature for 24 h, and weighed. The dried samples were later immersed in water for 24 h and weighed again. Thereafter, the WA of the sandcrete blocks was estimated and recorded. The WA test was also performed in triplicate for each experimental run and the mean value reported.

3. Result and discussion

3.1. Experimental results

Table 5 shows the summary of the S/N ratio mean laboratory results obtained with the designed Taguchi mixed level orthogonal array. It can be seen from Table 5 that the CS varies from a minimum value of $2.74N/mm^2$ to a maximum value of 4.07 N/mm^2. Similarly, in Table 5, the BD was observed to vary from a minimum value of 1797.97 kg/m^3 to a maximum value of 2083.51 kg/m^3. Lastly, for the WA, the minimum and maximum values were observed as 9% and 16% respectively.

3.2. Analysis of Taguchi results

3.2.1. Compressive strength

The mean and S/N ratio values of the CS are shown in Table 5. It is clear that the values of the CS for all the designed mix exceeded the recommended value of $1.5N/mm^2$ specified in the Nigerian Industrial Standard for non-load bearing sandcrete blocks [49]. Analysis of the results obtained from the orthogonal array is further executed to identify the optimal settings of the process parameters of the sandcrete block based on the results in Figures 6 and 7 and Table 6. The maximum values of CS and S/N ratio in Figures 6 and 7 indicate that the best setting of the process parameters can be obtained at levels 1, 3 and 1 for E/C ratio, W/C ratio and CSA content respectively. The result in Table 6 further illustrated that the order of relevance of the process parameters for improving the CS can be arranged in descending order as W/C ratio, E/C ratio, and CSA content.

ANOVA was conducted on the S/N ratio values to determine the process parameters which had statistically significant effect on the changes in the CS. The result is summarized in Table 7. The result shows that all the process parameters have a statistically significant effect on the CS S/N ratio at 0.05 alpha level. The relative percentage contributions of the process parameters to the CS S/N ratios are given, which shows that the W/C ratio contributed most to the strength variation, followed by the E/C ratio and then the CSA content. This result is consistent with that in

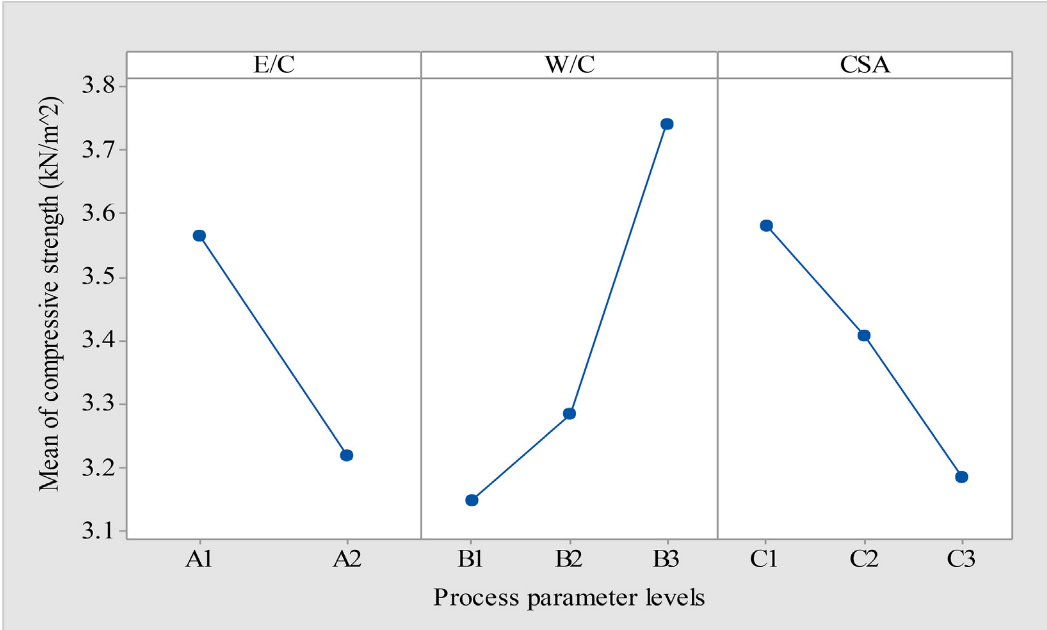

Figure 6. Parameter effect on the mean CS.

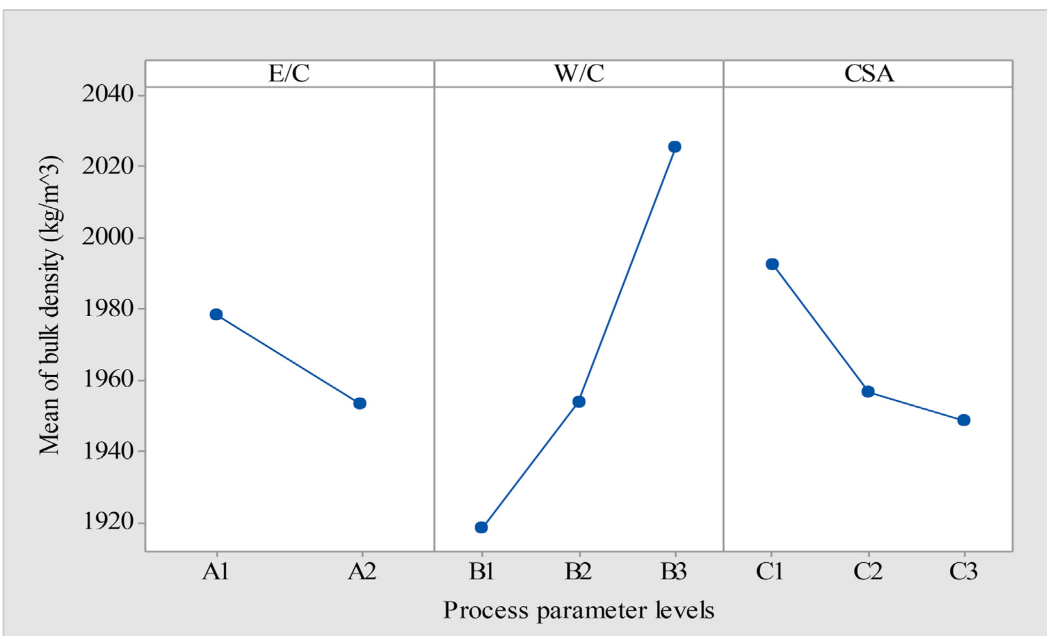

Figure 7. Parameter effect on the mean S/N ratio for the CS.

Table 6. The relative contributions of the process parameters observed can be attributed to the role they played in improving the CS values.

Improvement in the CS can be adduced to the rate of strength gain during cement hydration and pozzolanic reaction between LPC and CSA. The reaction is initiated with the hydration of cement on addition of water. Hence, it is expected that the quantity of available water necessary for the chemical reaction process is the most crucial factor in the rate of strength gain and formation of cementitious compounds such as CSH and CAH. The W/C ratio is therefore the controlling process parameter which determines the strength gain with time. It is known that more water is needed to sustain the strength gain, as with higher curing period (28 days) in the presence of moisture, more cementitious compounds are formed. This explains why level 3 of the W/C ratio is the optimum for CS gain. For the E/C ratio, level 2 was the optimum level because considering the as-cast surface of the block as a beam with more thickness for the centre web which serves as the internal support, the block can be able to sustain higher load due to higher support reaction at the center web [27]. The optimal level 1 obtained for the CSA can be explained in terms of the chemistry of the pozzolanic reaction, which led to long-term strength gain with curing. An important hydration product which results from the hydration reaction involving the alite (C_2S) and belite (C_3S) in the cement is portlandite ($Ca(OH)_2$). The portlandite is capable of reacting with the nano silica and alumina particles in the CSA to form nano phases of CSH and CAH. The pozzolanic reaction however, thrives on the availability of an alkaline medium, provided by the portlandite [63, 64, 65]. With exhaustion of the available portlandite due to reaction with more CSA, the alkalinity declines. This is usually associated with a gradual drop in strength [63, 64, 65]. This is what happened at

Table 6. Parameter effects on the CS and Taguchi S/N ratio.

Level	CS (kN/m^2)			Taguchi η (dB)		
	Parameter			Parameter		
	A	B	C	A	B	C
1	3.564*	3.148	3.580*	10.978*	9.901	11.028*
2	3.218	3.284	3.407	10.058	10.242	10.551
3	-	3.741*	3.185	-	11.410*	9.975
Δ	0.346	0.593	0.395	0.919	1.509	1.053
Rank	3	1	2	3	1	2

Key: Δ represents the difference between maximum and minimum values of the responses.
* represents the optimum level.

Table 7. ANOVA for CS S/N ratio.

Process parameter	DOF	SS	V	F-ratio	p-value	P
E/C ratio	1	3.804	3.804	9.253	0.010	19.4
W/C ratio	2	7.517	3.758	9.143	0.004	38.4
CSA	2	3.336	1.668	4.058	0.045	17.0
Error	12	4.933	0.411			25.2
Total	17	19.590				100.0

Table 8. Optimal level values for the CS.

Process parameter	Level	CS value (kN/m^2)	S/N response value (dB)
A	1	3.564	10.978
B	3	3.741	11.410
C	1	3.580	11.028

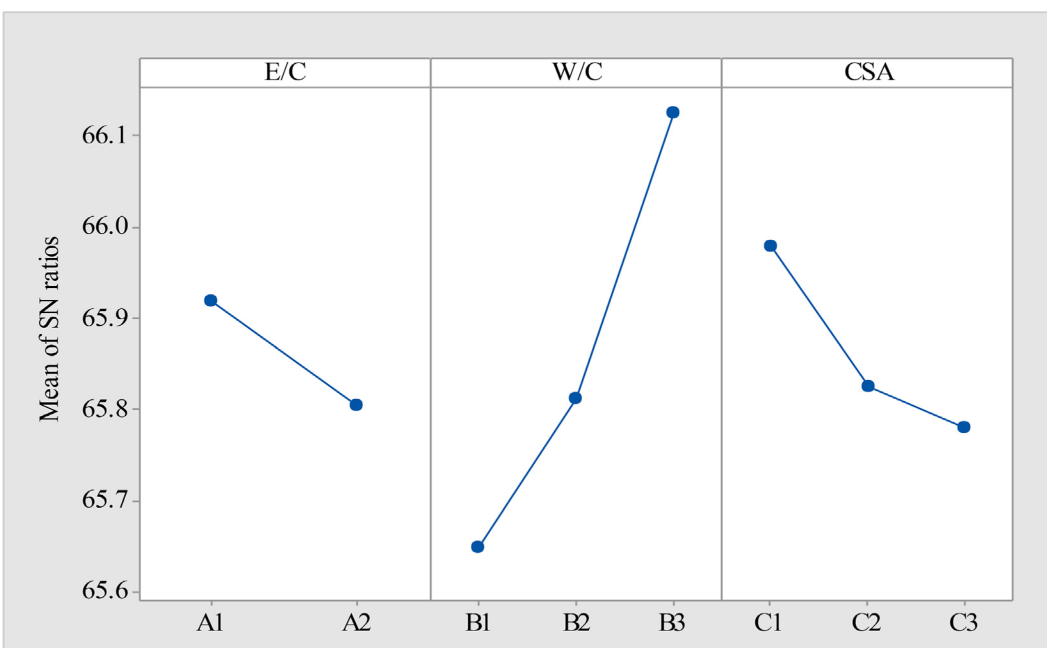

Figure 8. Parameter effect on the mean BD.

higher levels of the CSA; thus, the optimal strength was achieved at level 1, which provided favorable alkalinity for the pozzolanic reaction.

The values of the CS for the various optimum levels are summarized in Table 8. The optimum value of the CS is identified from Table 5 as $4.074 N/mm^2$, which can be predicted using the optimal level values in Table 8. The optimum value of the CS met the requirement of $3.5 N/mm^2$ stipulated for load bearing sandcrete blocks in the Nigerian Industrial Standard [49].

3.2.2. Bulk density

The mean BD and S/N ratio result is presented in Table 5. The result show that the designed experimental mix obtained using the mixed level

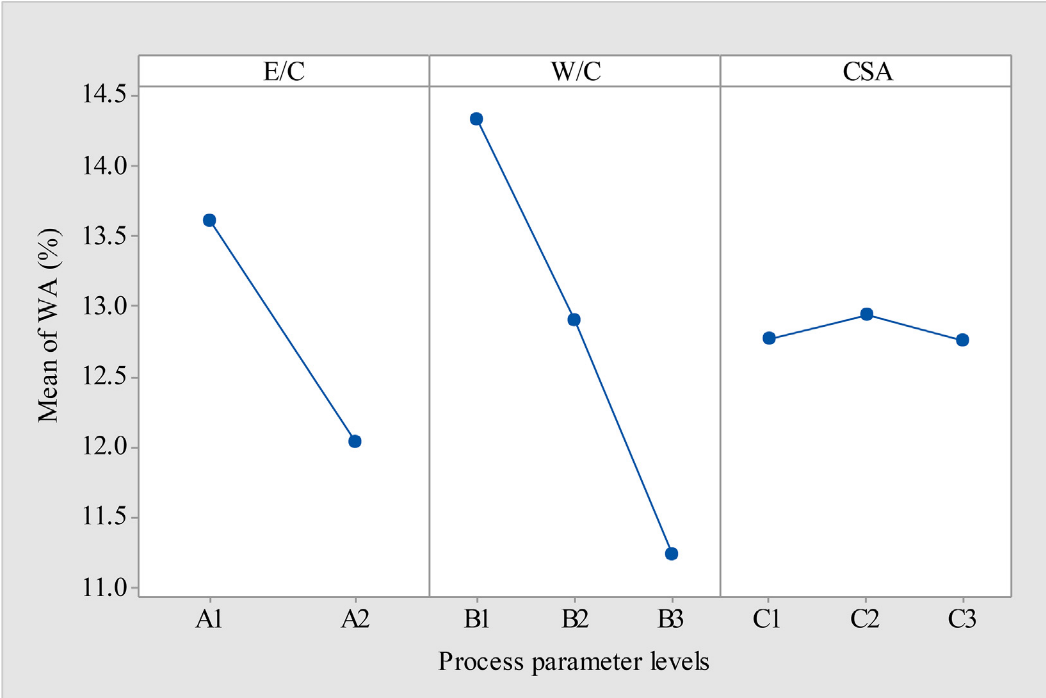

Figure 9. Parameter effect on the mean S/N ratio for the BD.

Table 9. Parameter effects on the BD and Taguchi S/N ratio.

Level	BD (kN/m^3)			Taguchi η (dB)		
	Parameter			Parameter		
	A	B	C	A	B	C
1	1978*	1918	1993*	65.92*	65.65	65.98*
2	1953	1954	1957	65.80	65.81	65.83
3		2026*	1948		66.12*	65.78
Δ	25	107	44	0.11	0.48	0.20
Rank	3	1	2	3	1	2

Key: Δ represents the difference between maximum and minimum values of the responses.
* represents the optimum level.

Table 10. ANOVA for BD S/N ratio.

Process parameter	DOF	SS	V	F-ratio	p-value	P
E/C ratio	1	0.058	0.058	0.676	0.427	3.0
W/C ratio	2	0.703	0.351	4.079	0.045	36.5
CSA	2	0.131	0.066	0.762	0.488	6.8
Error	12	4.933	0.086			53.7
Total	17	19.590				100.0

orthogonal array are reasonably satisfactory, based on the limit of 1800 kg/m^3 specified by the Nigerian Industrial Standard for sandcrete block quality [49]. An in-depth analysis of the BD using the Taguchi approach is executed using the results in Figures 8 and 9 and Table 9. Maximum values of the BD and S/N ratio are obtained at levels 1, 3 and 1 for the E/C ratio, W/C ratio and CSA content respectively. The process parameter effects presented in Table 9 reveal that the order of importance of the process parameters in ascending order is obtained as E/C ratio, CSA content and W/C ratio.

Table 11. Optimal level values for the BD.

Process parameter	Level	BD value (kg/m^3)	S/N response value (dB)
A	1	1978	65.92
B	3	2026	66.12
C	1	1993	65.98

Statistical analysis of the process parameter effects is presented in the ANOVA shown in Table 10. The result shows the relative percentage contribution of the process parameters to the BD S/N ratio values; and it is clear that the W/C ratio contributed most to the variation in the BD, followed by CSA content and then the E/C ratio. The result is consentient with that shown in Table 9. More so, only the W/C ratio had a statistically significant effect on the BD S/N ratio at 0.05 alpha level. As such, the optimum level for the W/C ratio ought to be used to achieve the desired

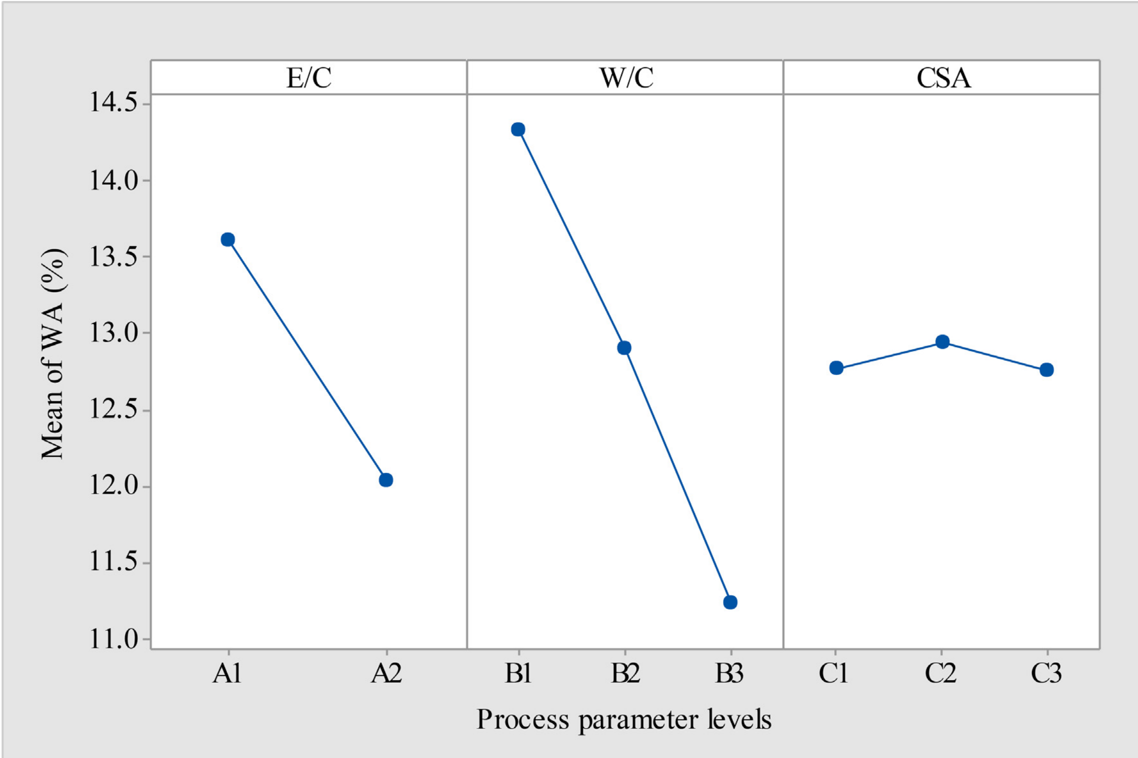

Figure 10. Parameter effect on the mean WA.

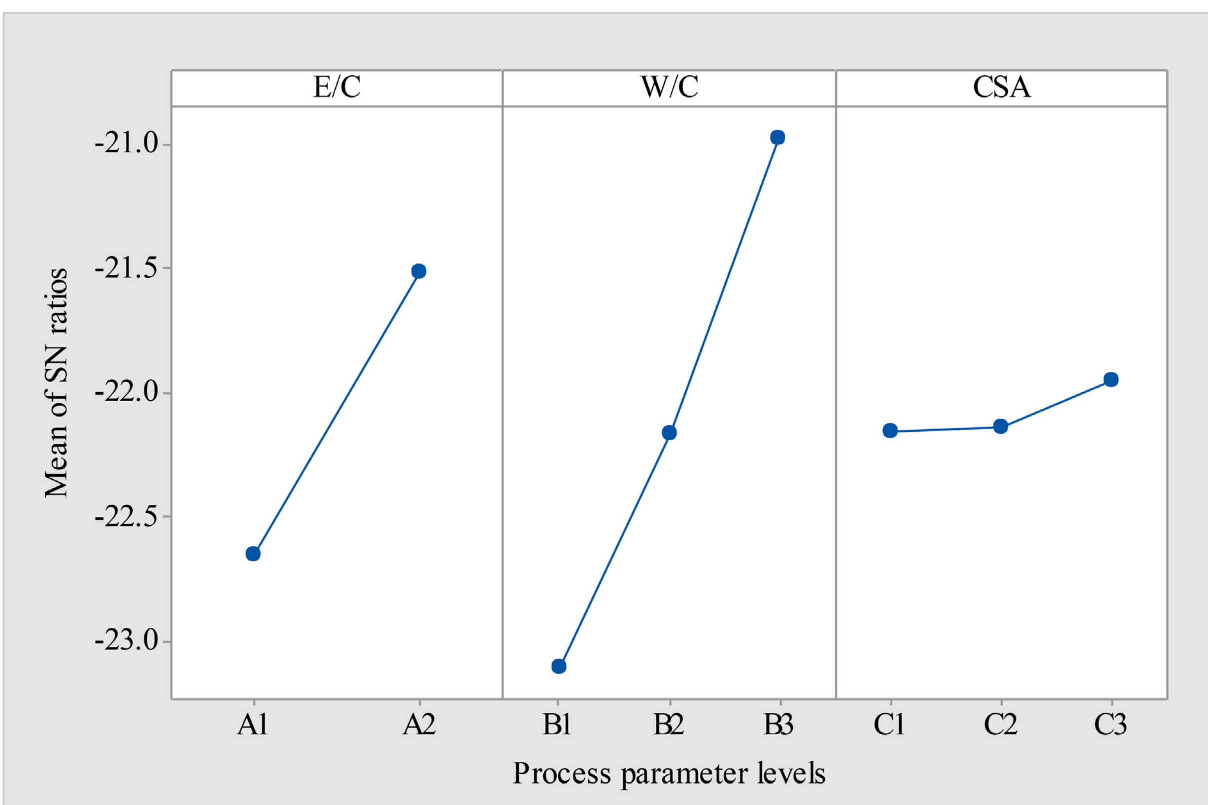

Figure 11. Parameter effect on the mean S/N ratio for the WA.

Table 12. Parameter effects on the WA and Taguchi S/N ratio.

Level	WA (%)			Taguchi η (dB)		
	Parameter			Parameter		
	A	B	C	A	B	C
1	13.62	14.34	12.7722	-22.65	-23.10	-22.15
2	12.04*	12.91	12.9444	-21.51*	-22.17	-22.14
3	-	11.23*	12.7667*	-	-20.97*	-21.95*
Δ	1.58	3.11	0.18	1.13	2.13	0.20
Rank	2	1	3	2	1	3

Key: Δ represents the difference between maximum and minimum values of the responses.
* represents the optimum level.

Table 13. ANOVA for WA S/N ratio.

Process parameter	DOF	SS	V	F-ratio	p-value	P
E/C ratio	1	5.766	5.766	3.825	0.074	15.3
W/C ratio	2	13.667	6.834	4.534	0.034	36.3
CSA	2	0.157	0.079	0.052	0.949	0.4
Error	12	18.088	1.507			48
Total	17	37.678				100

Table 14. Optimal level values for the WA.

Process parameter	Level	WA (%)	S/N response value (dB)
A	2	12.04	-21.51
B	3	11.23	-20.97
C	3	12.7667	-21.95

BD for the sandcrete blocks. The other process parameters with insignificant effect can be utilized as economy factors.

For instance, either of levels 1 or 2 for the E/C ratio can be utilized since its effect is statistically insignificant to the BD. However, level 1 of the E/C ratio, which requires less material due to its higher void of 42% as shown in Figure 3 would be preferable for economy. The values of the BD at the optimum level are shown in Table 11. These values can be utilized for prediction of the value of the optimum BD of 2093.5 kg/m^3, as shown in Table 5.

3.2.3. Water absorption

The result for the mean WA and S/N ratio is summarized in Table 5. The values range around the specified value of 12% recommended by the Nigerian Industrial Standard for sandcrete block [49]. The WA determines the long-term performance of the sandcrete block under severe exposure condition, such as water logging. It is crucial to identify the optimal setting of the process parameters required to achieve the optimum value of WA. To identify the optimal process parameter settings, Figures 10 and 11 and Table 12 are used. The maximum values of the S/N ratio in Figure 11 help to select the optimal process parameter levels, which minimizes the WA (Figure 10). The best setting was obtained at E/C ratio of 1:2, W/C ratio of 0.65 and CSA content of 20%. The result in Table 12 shows that the W/C ratio is the most relevant process parameter for the WA, followed by the E/C ratio and then, the CSA content.

To determine the process parameters, which significantly affected the WA, ANOVA was performed as shown in Table 13. At 0.05 alpha level, only the W/C ratio had statistically significant effect on the WA. The E/C ratio and CSA content can be considered as economy factors. For the CSA content for instance, the level 3 can be conveniently selected since it is better in terms of cost effectiveness because of the extent of partial replacement of cement. Also in terms of environmental friendliness, it encourages higher valorization of the CSA waste into a very useful cement-based material. More so, the use of a lower percentage of cement serves as an expedient means of mitigating the release of CO_2 associated with cement production, into the atmosphere.

The optimal process setting for the E/C ratio is level 2. This is due to the fact that the E/C ratio at level 2 had a void percentage of 38%, which limits the amount of water, trapped between the block hollow and thus, minimized the amount of water absorbed. Using the optimal settings of the process parameters, the optimum value of the WA is obtained as 10%. This value can be predicted using the optimal level values in Table 14 and is satisfactory, based on the requirement of the Nigerian Industrial Standard [49].

4. Conclusion

Cement-based materials are highly desirable in building and construction due to their strength and durability qualities. However in recent years, the affordability and environmental eco-friendliness of these materials cannot be readily ascertained. It is widely known that a high amount of CO_2 emission is associated with cement manufacturing, which promotes global warming.

In view of this, an attempt was made in the present study to develop a sustainable cement-based material using CSA, which is an agro-based waste material. Disposal of waste materials are generally associated with environmental degradation, such as landfill issues. The agro-based waste material was therefore utilized in the partial replacement of cement in sandcrete blocks due to cost effectiveness and environmental sustainability. Also, a modified sandcrete block mold with a higher void percentage and smaller E/C ratio was developed for cost effectiveness.

Taguchi's robust design was adopted for development of the sandcrete blocks in order to ensure adequate production quality, identify the optimal settings and significance of the process parameters on the sandcrete block properties including CS, BD and WA. The following conclusions can be drawn based on the results obtained:

- The developed sandcrete block mold with E/C ratio of 1:2 is crucial for producing high CS and density blocks, however, the WA tendency is slightly higher than that of the conventional block with E/C ratio of 1:1.
- All the process parameters had a statistically significant effect on the CS of the blocks at 0.05 alpha level. Hence, the optimal process

parameter settings must be adhered to in order to achieve the best CS in a robust manner.

- For the WA and BD, only the W/C ratio had a statistically significant effect on the sandcrete blocks at 0.05 alpha level and its optimal level setting must be used to ascertain quality sandcrete block production. On the other hand, the settings of the other process parameters can be rationally selected based on convenience.
- The optimum values of the responses achieved through Taguchi optimization satisfied the requirements of the Nigerian Industrial Standard. The blocks produced in the present study can be considered appropriate for walling in areas with potential for moisture exposure such as groundwater conditions and as load bearing masonry units in buildings.

Declarations

Author contribution statement

Chijioke Christopher Ikeagwuani & Donald Chimobi Nwonu: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Chiagoziem Kanayo Ugwu & Chukwudi Cajethan Agu: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors wish to appreciate the contributions of the anonymous reviewers for their input which improved the clarity of this paper. The assistance offered by Mr Okey Kalu during the laboratory tests is also greatly appreciated. Finally, the authors are grateful to Engr. Dr. Desmond Ewa who provided the Nigerian standard code used for the experimental test.

References

[1] K.B. Najim, I. Al-Jumaily, A.M. Atea, Characterization of sustainable high performance/self-compacting concrete produced using CKD as a cement replacement material, Construct. Build. Mater. 103 (2016) 123–129.

[2] A. Edalat-Behbahani, F. Soltanzazeh, M. Emam-Jomeh, Z. Soltanzadeh, Sustainable approaches for developing concrete and mortar using waste seashell, Eur. J. Environ. Civ. Eng. (2019).

[3] J.M. Carvalho, T.V. Melo, W.C. Fontes, J.O. Batista, G.J. Brigolini, R.A. Peixoto, More eco-efficient concrete: an approach on optimization in the production and use of waste-based supplementary cementing materials, Construct. Build. Mater. 206 (2019) 397–409.

[4] R.M. Kajaste, M. Hurme, Cement industry greenhouse gas emissions emanagement options and abatement cost, J. Clean Prod. 112 (2016) 4041–4052.

[5] M.B. Ali, M.S. Hossain, A review on emission analysis in cement industries, Renew. Sustain. Energy Rev. 15 (2011) 2252–2261.

[6] H.G. Lee, A. Hanif, M. Usman, J. Sim, H. Oh, Performance evaluation of concrete incorporating glass powder and glass sludge wastes as supplementary cementing material, J. Claen Prod. 170 (2018) 683–693.

[7] T.R. Naik, G. Moriconi, Environmental-friendly durable concrete made with recycled materials for sustainable concrete construction, CANMET/ACI Int. Symp. Sustain. Dev. Cem. Concr. 2 (2005).

[8] A. Hanif, Y. Kim, K. Lee, C. Park, J. Sim, Influence of cement and aggregate type on steam-cured concrete - an experimental study, Mag. Concr. Res. 69 (13) (2017) 694–702.

[9] J. Manasseh, A review of partial replacement of cement with some agro wastes, Nigeria J. Technol. 29 (2) (2010) 12–18.

[10] A. Mashaly, B.N. Shalaby, M.A. Rashwan, Performance of mortar and concrete incorporating granite sludge as cement replacement, Construct. Build. Mater. 169 (2018) 800–818.

[11] A.S. Dieb, D.M. Kanaan, Ceramic waste powder an alternative cement replacement - characterization and evaluation, Sustain. Mat. Technol. (2018).

[12] Y. Kim, A. Hanif, M. Usman, M.J. Munir, S.M. Kazmi, S. Kim, Slag waste incorporation in high early strength concrete as cement replacement environmental impact and influence on hydration & durability attributes, J. Clean. Prod. (2017).

[13] P. Nalobile, M.J. Wachira, J.K. Thiong'o, J.M. Marangu, Pyroprocessing and the optimum mix ratio of rice husks, broken bricks and spent bleaching earth to make pozzolanic cement, Heliyon 5 (9) (2019), e02443.

[14] M.A. Noaman, M.R. Karim, M.N. Islam, Comparative study of pozzolanic and filer effect of rice husk ash on the mechanical properties and microstructure of brick aggregate concrete, Heliyon 5 (6) (2019), e01926.

[15] G.C. Cordeiro, P.V. Andreao, L.M. Tavares, Pozzolanic properties of ultrafine sugar cane bagasse ash produced by controlled burning, Heliyon 5 (10) (2019), e02566.

[16] A. El Mir, S.G. Nehme, J.J. Assaad, Durabilty of self-consolidating concrete containing natural waste perlite powders, Heliyon 6 (1) (2020), e03165.

[17] E.M. Opiso, R.P. Supremo, J.R. Perodes, Effects of coal fly ash and fine sawdust on the performance of pervious concrete, Heliyon 5 (11) (2019), e02783.

[18] A. Pandey, B. Kumar, Evaluation of water absorption and chloride ion penetration of rice straw ash and microsilica admixed pavement quality concrete, Heliyon 5 (8) (2019), e02256.

[19] I.K. Cisse, M. Laquerbe, Mechanical characterisation of filler sandcretes with rice husk ash additions - study applied to Senegal, Cement Concr. Res. 30 (2000) 13–18.

[20] J.O. Odigure, Deterioration of long-serving cement-based sandcrete structures in Nigeria, Cement Concr. Res. 32 (2002) 1451–1455.

[21] B.K. Baiden, C.K.O. Asante, Effects of orientation and compaction methods of manufacture on strength properties of sandcrete blocks, Construct. Build. Mater. 18 (2004) 717–725.

[22] B. Mohammed, C.R. Cheeseman, Use of oil drill cuttings as an alternative raw material in sandcrete blocks, Waste Biomass Valor 2 (2011) 373–380.

[23] B.K. Baiden, M.M. Tuuli, Impact of quality control practices in sandcrete blocks production, J. Archi. Eng. ASCE 10 (2) (2004) 53–60.

[24] O.J. Uzoamaka, Some factors which affect the crushing strength of snadcrete blocks, Mater. Struct. 10 (55) (1977) 45–48.

[25] K.G. Kolovos, P.G. Asteris, S. Tsivillis, Properties of sandcrete mixtures modified with metakolin, Eur. J. Environ. Civ. Eng. (2016).

[26] A. Omoregie, Optimum compressive strength of hardened sandcrete building blocks with steel chips, Buildings 3 (2013) 205–219.

[27] C.C. Ikeagwuani, I.N. Obeta, D.C. Nwonu, V.A. Onyia, J.N. Ezema, Partial replacement of cement with coconut shell ash in sandcrete block, Res. J. Appl. Sci. Eng. Technol. 15 (6) (2018) 206–211.

[28] J.O. Akinyele, I.O. Toriola, The effect of crushed plastic waste on the structural properties of sandcrete blocks, Afr. J. Sci. Technol. Innov. Dev. (2018).

[29] Y.D. Amartey, J.K. Taku, B.H. Sada, Optimization model for compressive strength of sandcrete blocks using cassave peel ash (CPA) blended cement mortar as binder, Kathmandu Univ. J. Sci. Eng. Technol. 13 (II) (2017) 1–14.

[30] D.C. Okpala, Some engineering properties of sandcrete blocks containing rice husk ash, Build. Environ. 28 (3) (1993) 235–241.

[31] A.A. Raheem, O.K. Sulaiman, Sawdust ash as partial replacement for cement in the production of sancrete hollow blocks, Int. J. Eng. Res. Afr. 3 (4) (2013) 713–721.

[32] R. Roy, A Primer on the Taguchi Method, Van Nostrand Reinhold International company limited, New york, 1990.

[33] M. Nalbant, H. Gokkaya, G. Sur, Application of Taguchi method in the optimization of cutting parameters for surface roughnes in turning, Mater. Des. 1379–1385 (28) (2007).

[34] G. Taguchi, Taguchi on Robust Technology Development Bringing Quality Engineering Upstream, Amer Society of Mechanical ed., New York: ASME Press series on international advances in design and productivity, 1993.

[35] G. Taguchi, S. Chowdhury, Y. Wu, Taguchi Quality Handbook, Wiley-Interscience, 2004.

[36] S. Gunes, E. Manay, E. Senyigit, V. Ozceyhan, A Taguchi approach for optimization of design parameters in a tube with coiled wire inserts, Appl. Therm. Eng. 31 (2011) 2568–2577.

[37] N. Imsap, P. Luangpaibon, A comparative study of analysing transformed and noisy data in Taguchi orthogonal arrays, in: Proceedings of the International Multiconference of Engineers and Computer Scientists, IMECS 2015, March 18-20, Hong Kong, 2015.

[38] R.K. Roy, Design of Experiments Using the Taguchi Approach; 16 Steps to Product and Process Improvement, John Wiley & Sons. Inc, New York, 2001.

[39] M. Kurt, E. Bagci, Y. Kaynak, Application of Taguchi methods in the optimiation of cutting parameters for surface finish and hole diameter accuracy in dry drilling process, Int. J. Adv. Manuf. Technol. 40 (2009) 458–469.

[40] Y. Kumar, H. Singh, Multi-response optimization in dry turning process using Taguchi's approach and utility concept, Proc. Mater. Sci. 5 (2014) 2142–2151.

[41] E. Teimortashlu, M. Dehestani, M. Jalal, Application of Taguchi method for compressive strength optimization of tertiary blended self-compacting mortar, Construct. Build. Mater. 190 (2018) 1182–1191.

[42] M. Olivia, H. Nikraz, Properties of fly ash geopolymer concrete designed by Taguchi method, Mater. Des. 36 (2012) 191–198.

[43] A. Bagheri, A. Nazari, Compressive strength of high strength class C fly ash-based geopolymers with reactive granulated blast furnace slag aggregates designed by taguchi method, Mater. Des. 54 (2014) 483–490.
[44] A. Kumar, D.K. Soni, Effect of calcium and chloride based stabilizer on plastic properties of fine grained soil, Int. J. Pavem. Res. Technol. 12 (2019) 537–545.
[45] B. Lafifi, A. Rouaiguia, N. Boumazza, Optimization of geotechnical parameters using Taguchi's design of experiment (DOE), RSM and desirability function, Innov. Infrastr. Solut. 4 (35) (2019) 1–12.
[46] B.V. Dharmendra, S.P. Kodali, B.N. Rao, A simple and reliable Taguchi approach for multi-objective optimization to identify optimal process parameters in nano-powder-mixed electrical discharge machining of INCONEL800 with copper electrode, Heliyon 5 (8) (2019), e02326.
[47] R.M. Dodo, T. Ause, T.E. Dauda, U. Shehu, A.P.I. Popoola, Multi-response optimization of transesterification parameters of mahogany seed oil using grey relational analysis in Taguchi method for quenching application, Heliyon 5 (8) (2019), e02167.
[48] BS 812 - Part 2, Methods for Determination of Specific Gravity, British standard institution, 1995.
[49] NIS 978, Standard for Sandcrete Block, Standards Organisation of Nigeria, 2017.
[50] NIS 444-1, Composition, Specification and Conformity Criteria for Common Cements, Standard Organisation of Nigeria, 2003.
[51] M. Joel, I.D. Mbapund, Comparative analysis of the properties of concrete produced with Portland limestone cement (PLC) grade 32.5N and 42.5R for use in rigid pavement work, Global J. Eng. Res. 15 (2016) 17–25.
[52] C.C. Ikeagwuani, Comparative assessment of the stabilization of lime-stabilized lateritic soil as subbase material using coconut shell ash and coconut husk ask, Geotech. Geol. Eng. 37 (2) (2019) 3065–3076.
[53] E.A. Tejano, State of the art of coconut coir dusk utilization (general overview), in: Paper Presented during the National Workshop on Waste Utilization, Coconut Husk, Philippine Coconut Authoity, Diliman, Quezon City, Philippines, 1984.
[54] ASTM C618-12a, Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in concrete, American Society for Testing and Materials, West Conshohocken, PA, 2012.
[55] Y.R. Amarnath, Properties of concrete with coconut shells as aggregate replacement, Int. J. Eng. Invent. 1 (6) (2012) 21–31.
[56] M.S. Phadke, Quality Engineering Using Robust Design, Prentice-Hall: Engle-wood Cliffs, NJ, 1989.
[57] M.H. Shahavi, M. Hosseini, M. Jahanshahi, R.L. Meyer, G.N. Darzi, Clove oil nanoemulsion as an effective antibacterial agent: taguchi optimization method, Desalinat. Water Treatm. (2015) 1–12.
[58] S. Chamoli, A Taguchi approach for optimization of flow and geometrical parameters in a rectangular channel roughened with V down perforated baffles, Case Stud. Therm. Eng. 5 (2015) 59–69.
[59] BS 2028, Precast concrete Masonry Units, British Standard Institute (BSI), London, 1975.
[60] BS EN 12390, Part 3, Testing hardened concrete: compressive strength of test specimens, in: British Standard, Brussels, 2002.
[61] BS EN 12390, Part 1, Testing hardened concrete: shape, dimensions and other requirements for specimens and moulds, in: British Standard, Brussels, 2000.
[62] BS 1881, Part 122, Testing concrete: method for determination of water absorption, in: British Standard, London, 1983.
[63] A. Al-taie, M. Disfani, R. Evans, A. Arulrajah, S. Horpibulsuk, Impact of curing on behaviuor of basaltic expansive clay, Road Mater. Pavement Des. 19 (2016).
[64] C.C. Ikeagwuani, D.C. Nwonu, Resilient modulus of lime-bamboo ash stabilized subgrade soil with different compactive energy, Geotech. Geol. Eng. 37 (2019) 3557–3565.
[65] D.C. Nwonu, C.C. Ikeagwuani, Evaluating the effect of agro-based admixture on lime-treated expansive soil for subgrade material, Int. J. Pavement Eng. (2019) 1–15.