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Influence of Cement Content and Compaction Pressure on the Mechanical Properties of Sandcrete Blocks

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Abstract

In this study, the influence of cement content and compaction pressure on the unit weight, water absorption, and compressive strength of sandcrete blocks were evaluated. To achieve this,25 cubes of sandcrete blocksmeasuring 150mm × 150mm × 150mm were produced with different amounts of cement content by volume (20%, 25%, 30%, 35%, and 40%) and different compacting pressures (0, 0.489, 2.444, 4.889, and 7.333 in N/mm^2). After 28 days of curing,the cube samples were subjectedto a compressive strength test and water absorption test. The findings show that the weight and compressive strength of the sandcrete cubes investigated increases with increasing compacting pressure and cement content, whereas the water absorption decreases with increase in compacting pressure and cement content. Furthermore, statistical analysis of the data from the study showed that compacting pressure is more statistically significant to the compressive strength of sandcrete blocks than cement content. Therefore, sandcrete block manufacturers can take advantage of increased compaction pressure to meet technical requirements in the production of sandcrete blocks.

1.0. Introduction

Sandcrete is a composite material made up of fine aggregate (sand), cement, and water mixed in the right proportions [1][2][3]. Because coarse aggregate is not included in the mix, it differs from concrete in terms of material composition, and it also differs from mortar in that it has no slump. The material can be used to make masonry blocks and can also be used as a binder for precast units before they set and harden. Sandcrete blocks are commonly used to create partitions or load-bearing walls in buildings [4][5]. When used as load-bearing elements, they convey structural loads from structural elements above to the foundations. As a result, sandcrete blocks are often deemed acceptable and adaptable in the construction of buildings. However, for quite some time, the bulk of sandcrete blocks used in developing nations, particularly in Sub-Saharan Africa, have consistently failed to meet local and international specifications. The bulk of sandcrete blocks in use in Nigeria's construction industry, for example, do not match the Nigerian Federal Ministry of Works' specification [6][7]. Previous investigations in Nigeria have also indicated that these sandcrete blocks function poorly, with compressive strengths significantly below the required standards [8][9]. Even after being carried, some of these blocks frequently fail due to their own

weight. According to Abdullahi [10], the quality of sandcrete blocks varies due to the various production methods used and the qualities of constituent materials.
As a result, it is not unusual to witness a lot of building failures, especially failures of these blocks' walls. The high failure rates of building structures in Nigeria have also been linked to inadequate quality control and the use of substandard building materials, according to several studies. The failure of constituent materials and the interactions of materials within structural units cause structural failure.
Several factors, including the effect of fine aggregate combinations on particle size distribution, grading parameters, and sandcrete block compressive strength, have been explored to this goal [9][11][12]. The influence of vibration time on the compressive strength of hardened sandcrete construction blocks was also investigated by Uzoamaka [13]. The main purpose of this study is to demonstrate how altering cement and compacting pressure can be used to improve the compressive strength of sandcrete hollow blocks and cubes, as well as to determine the range of cement content and compacting pressure for optimum compressive strength.
Depending on the amount of production, the availability of tools, and the cost-effectiveness of the production, two ways of compaction are discovered to be used in this study. Machine compaction and hand compaction are two of these ways. For large-scale and commercial production, machine compaction is used, while hand compaction is used for small-scale projects. Usually, sandcrete blocks, which are usually hollow, are made on a large scale with a vibrating machine and on a small scale with a hand mould [14].
Afolayan [15] investigated effect of water-cement ratio on the compressive strength of sandcrete block blended with sawdust ash (SDA). In the study, varying proportions of sawdust ash was used to partially replace Ordinary Portland Cement (OPC) in the rations of 0%, 5%, 10%, 15% and 20%). Sandcrete cubes were made with a 1:4 mix ratio and water-cement ratios of 0.40, 0.50, 0.55, and 0.60, respectively. From the study, the compressive strength of blocks at 28 days was 3.80N/mm^2 for 5 percent SDA and 3.50N/mm^2 for 5% SDA at water-cement ratios of 0.55 and 0.60, respectively. At water-cement ratios of 0.55 and 0.60, the compressive strength of 10% SDA was 2.87N/mm^2 and 3.10N/mm^2, respectively. The compressive strength of the 5% and 10% replacements is greater than the necessary 2.00N/mm^2 specified by the Nigerian National Building Code [14] for non-load bearing walls. Sandcrete blocks with up to 10% SDA replacement at water-cement ratios of 0.55 and 0.60 can be used for non-load bearing walls based on these findings. In another related study on sustainable sandcrete block production, Ikeagwuani [17] used the Taguchi method to investigate the process parameters optimization for eco-friendly high strength sandcrete blocks.

Rasheed and Akinleye [18] investigated the effects of production method on the compressive strength of sandcrete blocks produced in Nigeria. The production methods considered in the study were manual compaction, hand ramming, and power operated method. The study showed that compaction has a very significant effect on the compressive strength of sandcrete block, with blocks made using a vibrating machine having the maximum compressive strength when compared with other production methods. Baiden and Asante [19] evaluated the three methods of concrete production with the view of assessing their impact on the strength of the concrete. In the study, it was observed that for all the compaction methods employed, different strengths of concrete were produced. The block production methods investigated in the study were;

1. Hand ramming compaction moulds.
2. Manual tamping compaction frame.
3. Motorised vibration machine.

The bulk densities of all the block samples produced by the manual mode of compaction (Hand ramming and Manual Tamping) were below the acceptable BS minimum with the exception of the vertical orientation of the hand ramming method. However, the study shows that only the motorised vibration compaction in the vertical orientation meets the acceptable standards. Odeyemi [20] also observed that the average compressive strength of manually produced blocks and machine compacted blocks at 28th day of curing were 2.83N/mm^2 and 2.96N/mm^2 respectively. This result revealed that machine compacted blocks have a higher compressive strength than the manually compacted blocks.

Literature is scanty on a deliberate attempt to measure the actual compaction pressure that is applied during the production of sandcrete blocks. This is so because during the hand ramming of blocks (manual production), it will be challenging to measure the actual pressure applied since it will vary from individual to individual, and the type of equipment used. Another interesting approach that could have been adopted is to measure the compaction energy applied, similar to the method that is adopted in the laboratory compaction of soils. The variables to consider in this case are the weight of the rammer, the height of the fall, the number of blows/falls, the number of layers, and the volume of the mould.

In this study, an automated improvisation has been adopted by taking advantage of the 'stress controlled' capability of the universal testing machine. The magnitude of force to be applied by the piston of the machine can be controlled and specified, while the area of the force can be determined by considering the size of the plate provided on top of the specimen. With this, the compacting pressure of a sandcrete sample in a 150 x 150 mm mould can be varied by altering the applied force. This can give a good indication of the effect of compacting pressure on the strength of sandcrete blocks.

The aim of this study, therefore, is to determine the effect of compacting pressure and cement content (mix-ratio) on the strength, density, and absorption of sandcrete blocks. The knowledge from this study can be used in the design of tamping machines for block production.

2.0. Methodology

The sandcrete blocks used for this study were produced from the mixture of cement, fine aggregates and potable borehole water. The cement used in the study is Portland Limestone Cement grade 42.5N (Dangote brand) conforming to CEM II, NIS 444-1[21] while the fine aggregates were sharp sand sourced from Amansea River in Awka, Anambra State Nigeria.

The aggregates used in the study were sampled and prepared in the laboratory according to BS EN 932-1:1999 [22] and BS EN 932-2:1999[23] standards. Subsequently, they were subjected to specific gravity, sieve analysis, moisture absorption, and bulk density tests in order to determine their physical properties. The specific gravity and moisture adsorption test for the fine and coarse aggregates was carried out in accordance with the requirements of BS EN 1097-6:2013 [24]. The sieve analysis test of the coarse and fine aggregates was done in accordance with the requirements of BS EN 933-1:2012 [25]. The bulk density test was done in accordance with BS EN 772-13:2000 [26]. Batching of the sandcrete mix (sand and cement) was done by volume using a container of known volume on varying percentages of 20%, 25%, 30%, 35%, and 40% of cement to sand. A trial batch was first prepared to be used in the calculation of the total quantity of constituent materials for making the number of cubes required. The different constituent materials of cement and sand were prepared and mixed manually using a shovel until a homogenous mix was obtained. The working process involved mixing the constituent materials thoroughly before adding the prescribed

quantity of water and then mixed further to produce fresh sandcrete. A total of 25 cubes were produced for this study and were cured in the laboratory by water sprinkling.
The compacting pressure was evaluated in the laboratory by placing the mould with fresh sandcrete under the piston of a compressive strength test machine. A 150 × 150 mm steel plate was placed under the piston in order to distribute the force of the piston to the fresh sandcrete. A stress controlled approach was adopted, where the force applied was specified, and the compacting (compressing) pressure determined as follows;

$$\text{Compacting Pressure} = \frac{Applied\ Pressure\ (kN)}{Area\ of\ plate\ (mm^2)} \quad (1)$$

The water absorption test of the samples was done in accordance with the requirements of BS EN 772-11:2000 [27] and the compressive strength test in accordance with the requirements of BS EN 772-1:2000[28].

3.0. Results and Discussion

The results of the particle size distribution analysis of the river sand are shown in Figure 2. The specific gravity results showed that the specific gravity of the fine aggregate was 2.61.

Table 1: Sieve Analysis Results of the Fine Aggregates Used (Sand)

Sieve size	Weight Retained(g)	% Weight Retained	Cumulative % Retained	Cumulative% Passing
4.75mm	1.09	0.218	0.218	99.782
2.00mm	9.00	1.80	2.018	97.982
1.18mm	13.00	2.60	4.618	95.382
0.6 mm	106.00	21.20	25.818	74.182
0.425 mm	61.00	12.20	38.018	61.982
0.300 mm	92.00	18.40	56.418	43.582
0.150 mm	210.00	42.00	98.418	1.582
Pan	7.80	1.78	100.196	0.197
	500		100	

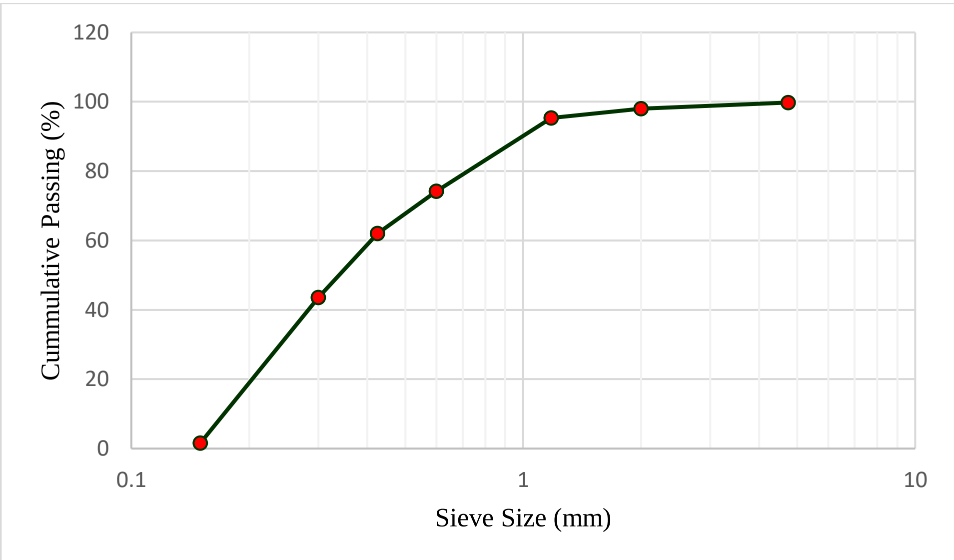

Figure 1: Particle size distribution curve of the fine aggregates

For the sharp sand used in the study, the fineness modulus was calculated from the particle size distribution results to be 2.26, while the coefficient of uniformity was calculated to be 2.22 was observed, which shows that sand is poorly/uniformly graded.

3.1 Weight of Sandcrete Cubes

The findings from the study showed that compaction pressure and cement content have a profound effect on the weight of the wet and dry concrete cubes. From Figures 2 and 3, it can be seen that as the compacting pressure and the cement-sand ratio increase, the weight of the cubes increases.

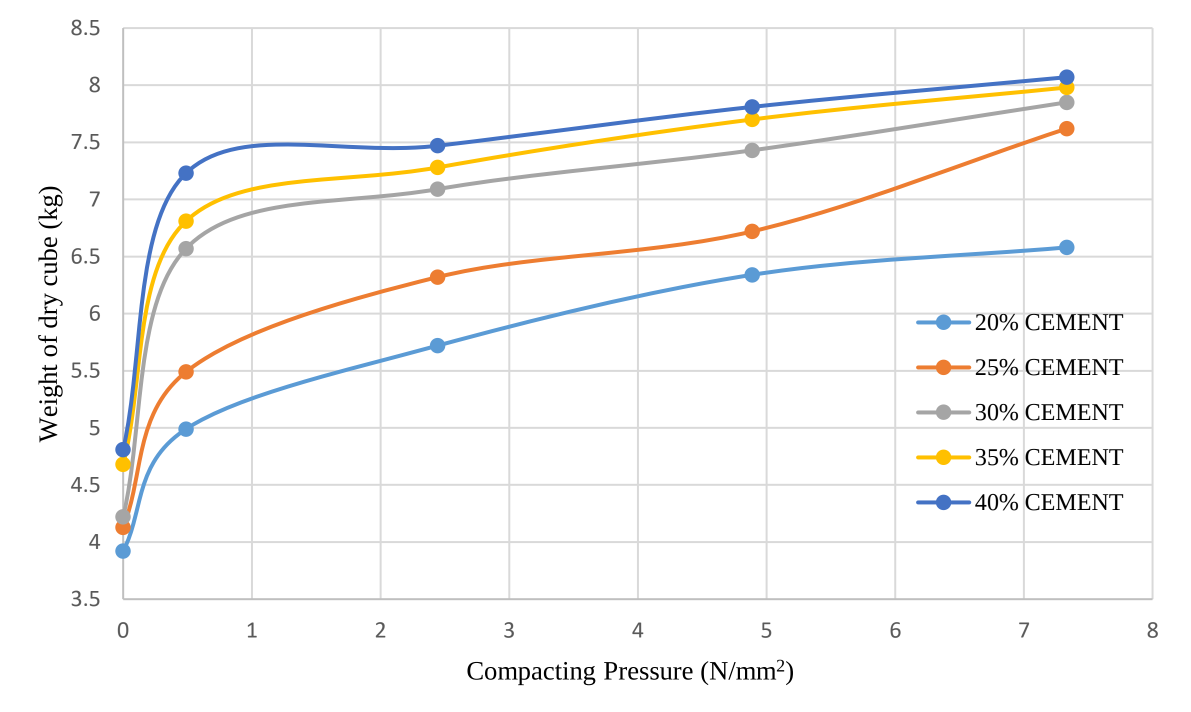

Figure 2: Variation of weight of dry cube with cement content and compacting pressure

At 20% cement content, the lowest values of weight were observed in the sandcrete cube samples when no significant compacting pressure was applied. When the compacting pressure was increased from 0 to 0.489 N/mm^2, sharp increase of about 21.4% in the weight of the dry cube was observed. The weight increase then increased gradually as the compacting pressure increased. The highest weight was observed at 7.33 N/mm^{2}compacting pressure and 40% cement content. The same trend in behavior was also observed when the wet cube samples were measured.

For the dry cube samples, ANOVA showed that both cement content and compacting pressure are statistically significant to the weight of the cube with *p-values* < 0.05 at 95% confidence level. However, the compacting pressure had more influence on the weight of the cube having a *p-value* of 8.74E-07 unlike cement content that has a *p-value* of 0.000664.

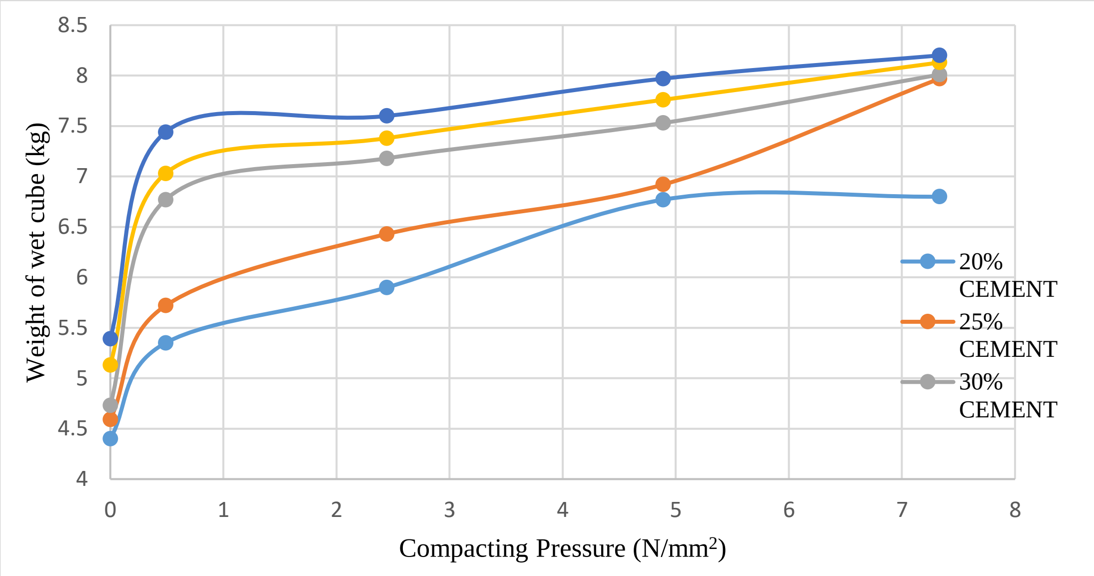

Figure 3: Variation of weight of wet cube with cement content and compacting pressure

3.2 Water Absorption

From the water absorption test carried out, the water absorption of the cubes decreased with increase in the compacting pressure as shown in Figure 4.A sharp decrease of about 40.98% was observed in the water absorption at 20% cement content when the compaction pressure was increased from 0 to 0.289 N/mm^2. The maximum water absorption recommended by the Nigerian Standard for sandcrete blocks was 12%. When no mechanical compacting pressure was applied on the cubes, a water absorption value of 12.2% was observed at 20% cement content. However, when the compacting pressure was increase to 0.289%, the water absorption reduced from 12.2% to 7.2% percent.

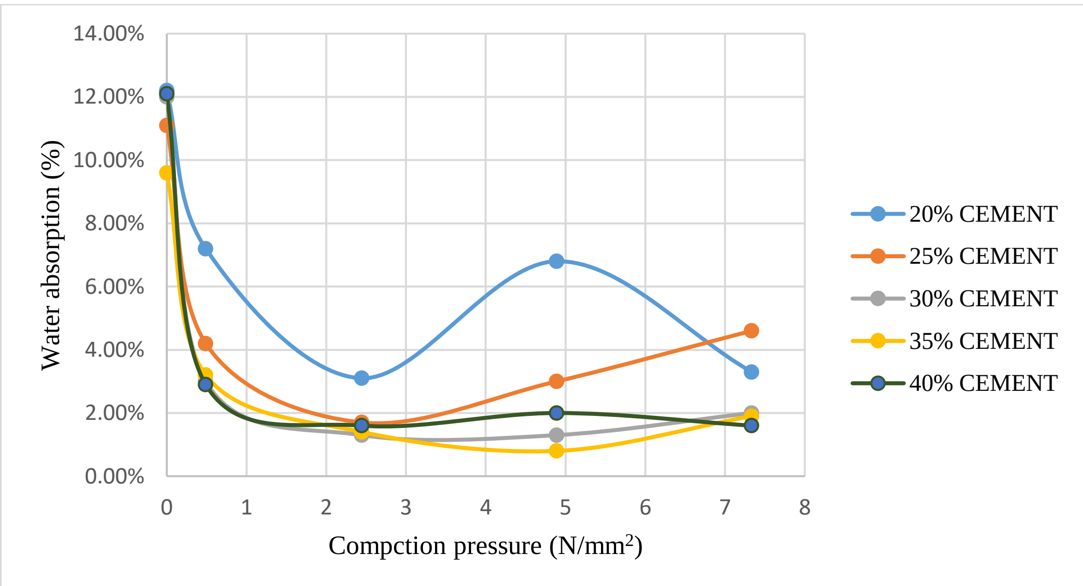

Figure 4: Variation of water absorption with cement content and compacting pressure

3.3 Compressive Strength

From the compressive strength result shown in Figure 5, the compressive strength of the sandcrete cube increased with the increase in compacting pressure and cement content after curing at 28 days. When the cube sample was not subjected to any electromechanical compaction, the compressive strength at 20% cement content after 28 days curing was 0.17 N/mm^2. However, when the compaction pressure was increased to 4.888 N/mm^2 (Compaction force of 11 kN), the compressive strength increased to 6.13 N/mm^2, which automatically satisfied the requirements of NIS 87:2000 [28].

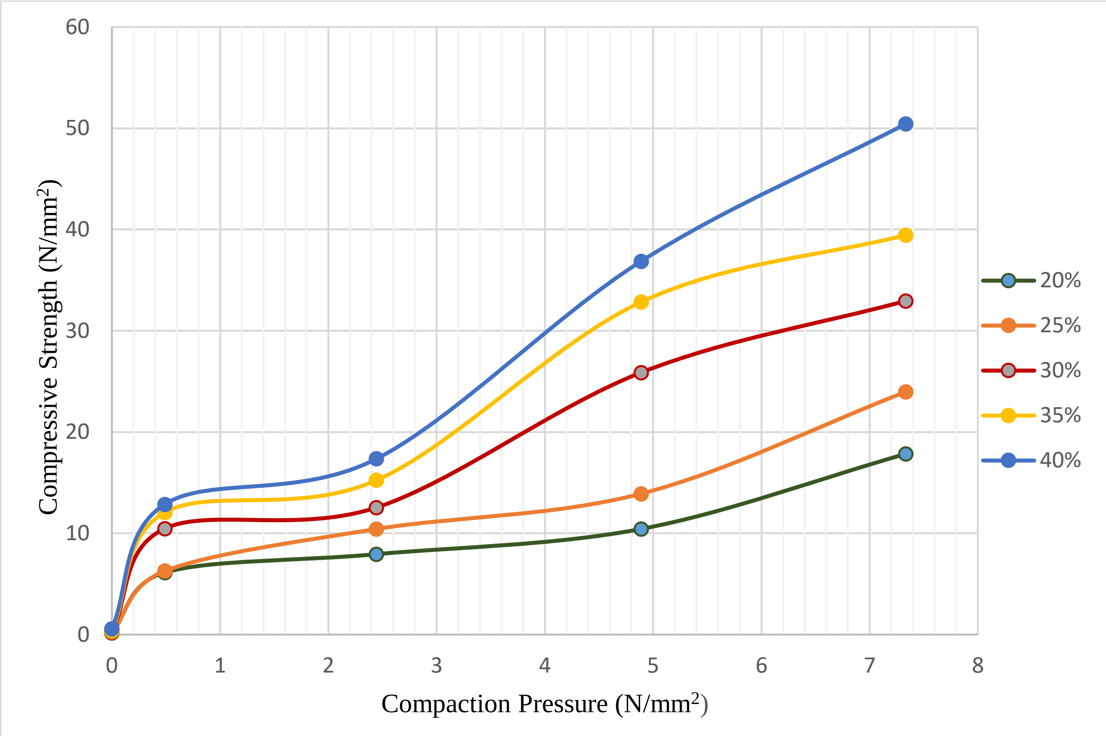

Figure 5: Variation of compressive strength with cement content and compacting pressure

The relationship between the compressive strength f_c (N/mm^2), compaction pressure C_p (N/mm^2) and cement content C_c (%) is given in the equation below;

$$f_c = 0.785C_c + 4.044C_p - 19.912\ (R^2 = 0.855) \quad (2)$$

The cement content and compaction pressure were observed to be statistically significant to the compressive strength of sandcrete blocks at 95% confidence level with *p-values* of 4.25173×10^{-5} and 8.22465×10^{-10} respectively. This showed that the compaction pressure was more statistically significant to the compressive strength of the sandcrete blocks that cement content.

However, since it will be more economically viable to increase compaction pressure than cement content, it is suggested that sandcrete block manufacturers take the advantage of adopting enhanced mechanical compaction and vibration in order to meet local production standards. For instance, at 20% cement content (1:5 mix ratio), the compressive strength increased from 0.17 N/mm^2 at 0 compaction pressure to 6.13 N/mm^2 at 0.488 N/mm^2 compaction pressure. This value of compressive strength clearly exceeds the requirements of NIS87:2000[28]. The typical mix ratio commonly adopted that meets the requirements of NIS 87:2000 is between 1:6 to 1:8. Therefore, the higher cement content adopted in this study appear impractical for most construction purposes, however, the study offers great insight on how the degree of compaction and cement content can influence the mechanical properties of sandcrete blocks.

4.0. Conclusion

This study investigated the effects of varying the cement content and the compacting pressure on the weight, compressive strength, and water absorption of sandcrete blocks. The study generally showed that the mechanical properties of sandcrete block can be greatly enhanced by increasing the compacting pressure and the cement content. However, due to the cost of cement, it was observed that it will be more economical to take advantage of the beneficial effects of increased compaction pressure, since it tends to be more statistically influential than cement content on the mechanical properties of sandcrete blocks. Based on the test and analysis of the study carried out, the following conclusions were made;

1. The compressive strength of the sandcrete cube increases with the increase in compacting pressure and cement content. At 20% cement content (mix ratio 1:5), a 96.5% increase in the compressive strength was observed after 28 days of curing when the mechanical compaction pressure was increased from zero to 0.4888 N/mm^2. When the compaction pressure was further increased to 2.444 N/mm^2, the compressive strength increased by 22.79%.
2. The water absorption values of sandcrete cubes decreases with increase in compaction pressure and cement content.At 20% cement content (mix ratio 1:5), a 40.98%decrease in the water absorption was observed after 28 days of curing when the mechanical compaction pressure was increased from zero to 0.4888 N/mm^2. When the compaction pressure was further increased to 2.444 N/mm^2, the water absorption furtherreduced by 56.9%.
3. The wet and dry weight (in effect density) of sandcrete cubes increases with increase in the cement content and compaction pressure.
4. From statistical analysis carried out (two-way ANOVA), it was observed that compaction pressure is more statistically significant on the mechanical properties of sandcrete blocks than cement content. Therefore, block manufacturers should take advantage of improved compaction and vibration in the production of sandcrete blocks in order to meet regulation standards.

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