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EXPERIMENTAL OPTIMISATION OF AGGREGATE GRADING AND WATER–CEMENT RATIO FOR SANDCRETE PRODUCTION

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Abstract: The aim of this study is to experimentally optimise the aggregate grading and water–cement ratio of sandcrete. River sand was sieved and separated into fine sand (particle sizes less than 1 mm), medium sand (1–2 mm particle size), and coarse sand (2–4 mm particle size). These particle size groups were blended in different proportions by weight to produce six combinations of sand particle sizes. For different water–cement ratios, simple mix proportions (by weight) were adopted for the different sand size combinations. Fresh sandcrete mixtures were cast in 150 mm × 150 mm × 150 mm moulds and adequately compacted. The 7– and 28–day density and compressive strength values of the sandcrete specimens were determined. It was found that a high coarse sand content tended to increase the bulk density of sandcrete. The compressive strength of the sandcrete specimens increased with an increasing proportion of coarse–grained sand. Specimens fabricated with lower water–cement ratio exhibited a significant compressive strength increase from 7 to 28 days than specimens produced with higher water–cement ratios. The optimum sand combination is 25% fine sand, 25% medium sand, and 50% coarse sand for all the evaluated water–cement ratios.

Keywords: aggregate grading, compressive strength, density, experimental optimisation, sandcrete

INTRODUCTION

In Nigeria and other West African countries, sandcrete is used for fabricating blocks used in building construction (Ettu et al., 2013). In these regions, sandcrete has become more widely used than traditional construction materials, such as laterite and mudcrete, for constructing walls in buildings. Wall units constructed with sandcrete may be designed as load–bearing or non–load–bearing elements, but sandcrete blocks are mainly used as partition members rather than load–bearing elements.

Sandcrete blocks may be hollow or solid, and different standard sizes of sandcrete are used, depending on the intended application. Sandcrete contains the conventional constituent materials used in concrete, except coarse aggregate. Sandcrete has a zero slump and typically contains coarser sand and a lower cement content than mortar. The zero slump of sandcrete makes it possible for the moulds to be removed immediately after mixing, compacting, and placing sandcrete blocks on a flat, horizontal surface. Hence, freshly manufactured sandcrete blocks are self–supporting.

Compressive strength and density are critical mechanical properties of sandcrete. Compressive strength is widely regarded as a reliable parameter for predicting other mechanical properties, while density directly correlates with the dead load in structural design.

Cement sandcrete blocks should have minimum compressive strength values of 1.85–3.45 MPa (NIS, 2007), depending on the block size and load application. Worryingly, commercially manufactured sandcrete blocks produced in different states of Nigeria suggest that the compressive strength of blocks generally fails to satisfy the NIS 87 (2007) strength requirements (Odeyemi et al., 2018; Ambrose et al., 2019; Tiough and Nande, 2019; Agbi et al., 2020; Anosike, 2021). In some cases, blocks fail under their self–weight, even when transported (Omoregie, 2013).

Although sandcrete blocks are mainly used as partition members rather than load–bearing members, it is still necessary to manufacture them according to standard specifications. In laboratory experiments, the strength of sandcrete can be determined using standard 100 or 150 mm cubes instead of blocks to save material costs. For example, the volume of a 450 mm × 100 mm × 225 mm solid block is three times greater than that of a 150 mm × 150 mm × 150 mm cube.

Sandcrete cubes tend to have a higher compressive strength than sandcrete specimens cast in block moulds; nevertheless, the strength of sandcrete cubes is related to that of sandcrete blocks. The strength and density of cement–based materials are influenced by several parameters, including aggregate size, aggregate grading, cement–aggregate proportion, and water–cement ratio. Some cases of building collapse recently observed in different regions of the country have been linked to low–quality construction materials and inadequate cement–

based mixtures (for example, attributed to poor aggregate grading and inappropriate mix ratios) (Odeyemi et al., 2019).

The influence of aggregate size and grading on the mechanical properties of sandcrete has been investigated in previous studies. Omoregie and Alutu (2006) assessed the strength of sandcrete blocks produced with sands obtained from different parts of Benin, Nigeria. They found that when higher silty sand is blended with lower silty sand, the compressive strength of the higher silty sand significantly increases with minimal cost effects. Oyekan (2008) observed that the compressive strengths of sandcrete blocks increased when coarse aggregate was used as a partial replacement for sand, and the optimum coarse aggregate content ranged from 25% for 5 mm aggregate to 35% for 15 mm aggregate. Ibearugbulem *et al.* (2018) investigated the physicomechanical behaviour of sandcrete produced with different sand grain size proportions and cement–sand mix ratios. They found that the grain size combination yielding the optimum sandcrete compressive strength contained 50% fine sand, 10% medium sand, and 40% coarse sand. Rimintsiwa *et al.* (2019) found that the higher the silt content of fine aggregate, the lower the compressive strength of the sandcrete block, as the silt tended to influence the cement properties.

The water–cement ratio for sandcrete should be selected such that it facilitates adequate cement hydration and enables the sandcrete blocks to stand unsupported after de–moulding. Some previous studies on sandcrete did not specify the water–cement ratio applied in mixing the sandcrete cubes or blocks (Ibearugbulem *et al.*, 2018; Anya and Osadebe, 2015). In such studies, water was gradually added to the cement–aggregate mixture with continuous mixing until a fresh homogenous mixture with a uniform colour was obtained. However, this procedure may lead to adding an excess amount of water during mixing, decreasing the sandcrete strength during the hardening process. Such an approach does not promote the replication of experimental studies. In addition, different sets of fine aggregates may have the same maximum particle size and material composition but exhibit different grading behaviour. Thus, there is a need to optimise the aggregate grading and water–cement ratio of sandcrete to save costs and improve material properties, such as strength and durability.

The aim of this study is to experimentally optimise the aggregate grading and water–cement ratio of sandcrete. This study seeks to determine the optimum sand size proportion that yields the maximum compressive strength of sandcrete. The compressive strength and density values of sandcrete specimens produced with different water–cement ratios and fine–aggregate size proportions were obtained.

MATERIALS

Binder

Grade 42.5 Portland–limestone cement manufactured to Nigerian Industrial Standards (NIS 444–1, 2003) was used as the binder. The cement was stored in bags and protected from dampness.

Water

Water obtained from a borehole in Imo State University, Nigeria, was used for preparing and curing the specimens. The water satisfied BS EN 1008 (2002) requirements.

Fine aggregate

River sand obtained from Otammiri River in Ihiagwa, Imo State, Nigeria, was used as the fine aggregate. The sand was white, well–graded, and coarse.

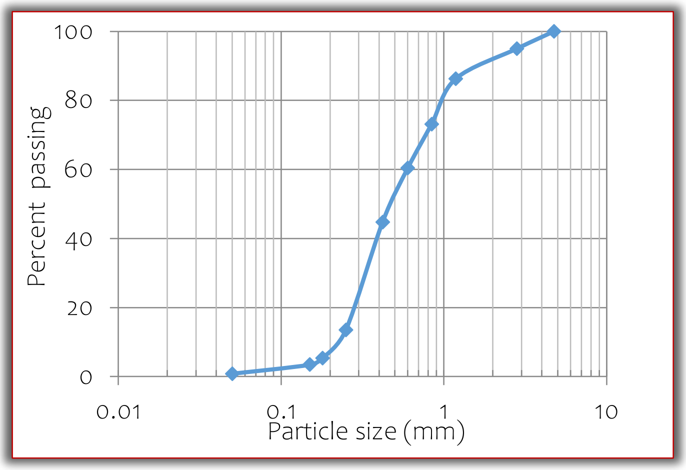

Figure 1. Particle size distribution of river sand

Figure 1 shows the particle size distribution of the river sand before sieving. The physical properties of the non–sieved sand are fineness modulus = 2.93, bulk density = 1490 kg/m^3, specific gravity = 2.65, and water absorption = 1.7%.

METHODS

Mix proportioning

The sand was first sieved and separated into different particle sizes (Table 1). A maximum grain size of 4 mm was adopted as the fine aggregate based on the specifications of BS EN 12620 (2002), and grains with sizes exceeding 4 mm were discarded. X_1, X_2, and X_3 represent fine, medium, and coarse sands, respectively. These three sets of particle sizes were blended in different proportions by weight to produce six combinations of sand particle sizes (Table 2). The combinations of the sand size were designed such that each sand proportion combination yielded a total sum of X_1, X_2, and X_3 equal to 100%. No single size range exceeded 50% of the total weight combination.

The constituent materials of the sandcrete were batched by weight. A cement–sand mix ratio of 1:6 was selected, as recommended by NIS 87 (2007) for sandcrete production. Three water–cement ratios (0.4, 0.5, and 0.6) were adopted in the experimental programme. For each water–cement ratio, simple mix proportions (by weight) were adopted for the different sets of sand particle sizes (Table 3).

Table 1. Particle sizes of sieved sand

Set no.	Particle size	Designation
1	$X_1 \leq 1$ mm	Fine sand
2	1 mm $\leq X_2 \leq$ 2 mm	Medium sand
3	2 mm $\leq X_3 \leq$ 4 mm	Coarse sand

Table 2. Percentages (by weight) for different sets of sand particle sizes

Proportion no.	X_1	X_2	X_3
P1	50%	50%	0%
P2	50%	25%	25%
P3	50%	0%	50%
P4	25%	50%	25%
P5	25%	25%	50%
P6	0%	50%	50%

Table 3. Mix proportioning of constituents of sandcrete specimens

w/c	Prop. no.	Water (kg)	Cement (kg)	Sand (kg)		
				X_1	X_2	X_3
0.4	P1	0.4	1	2	2	0
	P2	0.4	1	2	1.6	0.4
	P3	0.4	1	2	1.2	0.8
	P4	0.4	1	2	1	1
	P5	0.4	1	2	0.8	1.2
	P6	0.4	1	2	0.4	1.6
0.5	P1	0.5	1	2.5	2.5	0
	P2	0.5	1	2.5	2	0.5
	P3	0.5	1	2.5	1.5	1
	P4	0.5	1	2.5	1.25	1.25
	P5	0.5	1	2.5	1	1.5
	P6	0.5	1	2.5	0.5	2
0.6	P1	0.6	1	3	3	0
	P2	0.6	1	3	2.4	0.6
	P3	0.6	1	3	1.8	1.2
	P4	0.6	1	3	1.5	1.5
	P5	0.6	1	3	1.2	1.8
	P6	0.6	1	3	0.6	2.4

Preparation of sandcrete specimens

The cement and sand were first uniformly mixed in a dry state. The calculated amount of water, based on the selected water–cement ratio, was added was mixing was continued until a homogenous mixture of constant colour was obtained. The fresh sandcrete mixtures were cast in 150 mm × 150 mm × 150 mm moulds and compacted.

The moulds were initially oiled to minimise friction and reduce the difficulty of removing the moulds after the sandcrete set. Compaction was performed using a standard 16 mm tamping rod. Each side received 30 blows, resulting in 90 blows per cube. Six specimens were produced for each selected sand mix proportion and water–cement ratio, and 108 sandcrete cubes were fabricated.

The concrete specimens were retained in the moulds for 24 h, after which the moulds were removed. The de–moulded cube specimens were cured by sprinkling water twice a day (at 0900 and 1700 hours each day) for 7 and 28 days.

Tests

The 7– and 28–day density and compressive strength values of the sandcrete specimens were determined. On the day of testing, three specimens were subjected to tests for each particle size proportion and water–cement ratio. The density of each air–dried sandcrete cube was determined by dividing its mass by the volume. Tests to determine the compressive strength of the hardened cubes were performed according to BS EN 12390–3 (2009) specifications.

RESULTS AND DISCUSSION

Density

The density values of the 7– and 28–day sandcrete are listed in Tables 4 and 5, respectively. The densities of the 7–day sandcrete specimens ranged from 1700 to 2120 kg/m^3. The densities did not show a specific trend with variation in the water–cement ratio at 7 and 28 days.

The densities of the 28–day sandcrete cubes were slightly higher than those of the corresponding 7–day sandcrete cubes for a specific water–cement ratio and sand mix proportion. All the 28–day densities exceeded 2000 kg/m^3 and ranged between 2000 and 2300 kg/m^3. The densities obtained for the sandcrete specimens at 28 days are comparable to the sandcrete density values reported by Ibearugbulem *et al.* (2013). For the 28–day density, P5 and P6 specimens had higher density values than others; this increase could be attributed to the higher coarse sand contents of P5 and P6.

Table 4. Density values of sandcrete cubes at 7 days

Prop. no.	Density (kg/m^3)		
	w/c = 0.4	w/c = 0.5	w/c = 0.6
P1	1913	1802	1703
P2	1890	2002	1819
P3	2170	1903	1993
P4	2026	2066	1876
P5	2209	2108	2093
P6	2071	2064	2117

Table 5. Density values of sandcrete cubes at 28 days

Prop. no.	Density (kg/m^3)		
	w/c = 0.4	w/c = 0.5	w/c = 0.6
P1	2060	2179	2128
P2	2193	2083	2072
P3	2171	2063	2042
P4	2232	2133	2073
P5	2318	2219	2109
P6	2311	2210	2183

Compressive strength

The compressive strengths of the sandcrete specimens are listed in Tables 6 and 7. The 7–day compressive strength values for the different sand blends were 5.4–13.4, 6.1–13.03, and 6.3–13.0 MPa for the 0.4, 0.5, and 0.6 water–cement ratios, respectively (Table 6). For all the water–cement ratios, P5 had the highest compressive strength values, followed by P6, whereas P1 had the lowest compressive strength. For some sand mix proportions, the variation in the

7–day compressive strength was irregular. For P1 and P4, the 0.6 water–cement ratio yielded the maximum compressive strength; for P2 and P6, the 0.5 water–cement ratio resulted in the maximum strength; for P3 and P5, the water–cement ratio of 0.4 yielded the maximum strength.

Table 6. Compressive strength values of sandcrete cubes at 7 days

Prop. no.	Compressive strength (MPa)		
	w/c = 0.4	w/c = 0.5	w/c = 0.6
P1	5.91	6.05	6.16
P2	6.74	6.86	6.79
P3	7.25	7.38	7.68
P4	6.65	6.90	6.99
P5	13.32	13.03	12.96
P6	9.85	10.69	9.80

Table 7. Compressive strength values of sandcrete cubes at 28 days

Prop. no.	Compressive strength (MPa)		
	w/c = 0.4	w/c = 0.5	w/c = 0.6
P1	7.41	7.35	7.27
P2	8.56	8.26	8.09
P3	9.23	8.93	8.76
P4	8.11	8.01	7.89
P5	18.23	16.05	15.84
P6	16.50	13.69	11.96

The compressive strength values of the sandcrete specimens on the 28th day of curing were 7.4–18.3, 7.3–16.1, and 7.27–15.9 MPa for the 0.4, 0.5, and 0.6 water–cement ratios, respectively (Table 7).

Similar to the 7–day compressive strength results, P5 had the highest 28–day compressive strength for all water–cement ratios, followed by P6. P5 had higher compressive strength than P6 because the fine sand filled the voids formed by the medium and coarse sands in the sandcrete matrix. P1 had the lowest 28–day compressive strength. The increasing ranks of the sandcrete specimens based on their 28–day compressive strengths are as follows:

P1 < P4 < P2 < P3 < P6 < P5.

The ranking indicated that the specimens with increased coarse sand contents (50%) had higher compressive strengths than specimens with low (25%) and no (0%) coarse sand contents. Moreover, the variation in the water–cement ratio with the 28–day compressive strength was consistent; an increase in the water–cement ratio decreased the 28–day compressive strength of sandcrete specimens for all the sand mix proportions.

The 7–day compressive strength of cement–based materials can be expressed as a ratio or percentage of its corresponding 28–day compressive strength.

Figure 2 shows the percentage of the 7–day compressive strength of sandcrete compared to the corresponding 28–day compressive strength. The 7–day compressive strength of sandcrete was 60–90% of the corresponding 28–day compressive strength for all aggregate grades and water–cement ratios. The relatively high values might be attributed to the absence of coarse aggregate, which accelerated the fine aggregate–cement paste bond. The values of the 7–to–28–day strength ratio tended to increase with the water–cement ratio; this increase was higher for sandcrete specimens with higher proportions of coarse sand (P5 and P6). Thus, mixtures produced with lower water–cement ratios gained more strength from 7 to 28 days than mixtures produced with higher water–cement ratios.

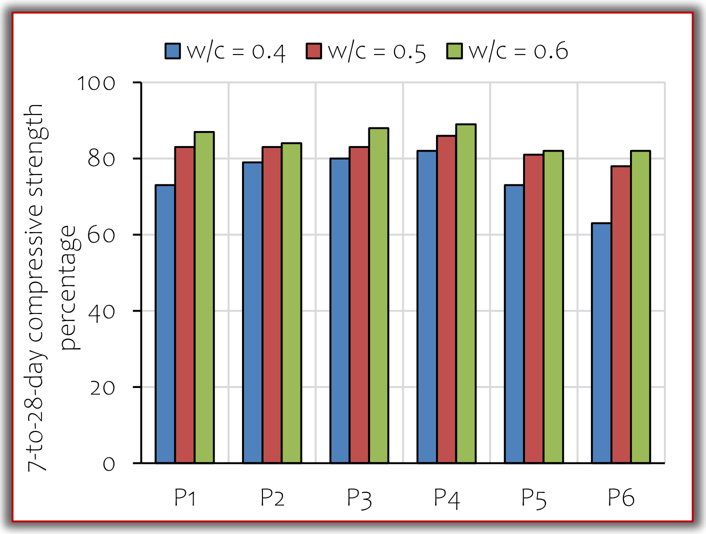

Figure 2. Percentage of 7–day compressive strength to 28–day compressive strength

CONCLUSIONS

In this study, the experimental optimisation of aggregate grading and water–cement ratio of sandcrete was investigated. The compressive strengths and densities of sandcrete specimens produced with different water–cement ratios and fine–aggregate size proportions were obtained. The following conclusions were drawn.

- A high coarse sand content tended to increase the bulk density of sandcrete, and the 28–day densities of all the sandcrete specimens exceeded 2000 kg/m^3.
- The compressive strength of the sandcrete specimens increased with an increasing proportion of coarse–grained sand.
- Specimens fabricated with lower water–cement ratio exhibited a significant compressive strength increase from 7 to 28 days than specimens produced with higher water–cement ratios.
- Based on the density and compressive strength values obtained in this study, the optimum sand combination is 25% fine sand (particle sizes less than 1 mm), 25% medium sand (1–2 mm particle size), and 50% coarse sand (2–4 mm particle size).

Sands used for cement sandcrete construction should be well–graded to optimise the physical and mechanical properties of sandcrete. The long–term mechanical properties of sandcrete, such as compressive strength, splitting tensile strength, and flexural strength, should be investigated in future studies. In addition, the use of industrial and agricultural by–products as pozzolana and supplementary cementitious materials, such as rice husk ash and fly ash, in sandcrete, should be assessed.

References

[1] Agbi, G. G., Akpokodje, O. I., and Uguru, H. (2020). Compressive strength of commercially produced sandcrete blocks within Isoko metropolis of Delta State, Nigeria. Turkish Journal of Agricultural Engineering Research, 1(1):91–103.

[2] Ambrose, E. E., Etim, R. K., and Koffi, N. E. (2019) Quality assessment of commercially produced sandcrete blocks in part of Akwa Ibom State, Nigeria. Nigerian Journal of Technology, 38(3):586–593.

[3] Anosike, N. M. (2021). Assessment of sandcrete blocks quality in Owerri, Imo State, Nigeria. Journal of Engineering Research and Reports, 21(1):15–24.

[4] Anya, C. U., and Osadebe, N. N. (2015). Effect of partial replacement of sand with quarry dust on the structural characteristics of sandcrete blocks. Nigerian Journal of Technology, 34(4):679–684.

[5] BS EN 1008 (2002). Mixing water for concrete — Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete. British Standards Institution, London.

[6] BS EN 12390–3 (2009). Testing hardened concrete — Compressive strength of test specimens. British Standards Institution, London.

[7] BS EN 12620 (2002). Aggregates for concrete. British Standards Institution, London.

[8] Ettu, L. O., Arimanwa, J. I., Njoku, F. C., Amanze, A. P. C., and Eziefula, U. G. (2013). Strength of blended cement sandcrete and soilcrete blocks containing sawdust ash and pawpaw leaf ash. International Journal of Engineering Inventions, 2(8):35–40.

[9] Ibearugbulem, O. M., Eziefula, U. G., and Opara, H. E., Physico–mechanical behaviour of sandcrete produced with different proportions of sand grain sizes. Engineering and Applied Science Research, 45(2):83–88.

[10] NIS 444–1 (2003). Quality standard for ordinary Portland cement — Part 1: Composition, specification and conformity criteria for common cements. Standards Organisation of Nigeria, Lagos.

[11] NIS 87 (2007) Standards for sandcrete blocks. Standards Organisation of Nigeria, Lagos.

[12] Odeyemi, S. O., Akinpelu, M. A., Atoyebi, O. D., and Orire, K. J. (2018). Quality assessment of sandcrete blocks produced in Adeta, Kwara State, Nigeria. Nigerian Journal of Technology, 37(1):53–59.

[13] Odeyemi, S. O., Giwa, Z. T., and Abdulwahab, R. (2019). Building collapse in Nigeria (2009–2019), causes and remedies – A review. USEP: Journal of Science and Engineering Production, 1(1):122–135.

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

[15] Omoregie, A., and Alutu, O. E. (2006). The influence of fine aggregate combinations on particle size distribution, grading parameters, and compressive strength of sandcrete blocks. Canadian Journal of Civil Engineering, 33(10):12–17.

[16] Oyekan, G. L. (2008). Single and mixed size coarse aggregates in sandcrete block production. 33rd Conference on Our World in Concrete and Structures, Singapore, August 25–27, 2008. [Online]

[17] Rimintsiwa, N. S., Muhammed, A., and Aminu, A. (2019). Effect of sand grading on the compressive strength of sandcrete block. The International Journal of Science and Technoledge, 7(2):105–121.

[18] Tiough, D. M., and Nande, V. M. (2019). An evaluation of the strength properties of commercially produced sandcrete blocks in Makurdi metropolis. International Journal of Education Development, 24(1):1–10.

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