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Physico-mechanical behaviour of sandcrete produced with different proportions of sand grain sizes

Owus M. Ibearugbulem[1)], Uchechi G. Eziefula*[2)] and Hyginus E. Opara[3)]

[1)]Department of Civil Engineering, Federal University of Technology, Owerri, Imo State, Nigeria
[2)]School of Engineering Technology, Imo State Polytechnic, Umuagwo, Imo State, Nigeria
[3)]Department of Civil Engineering, Imo State University, Owerri, Imo State, Nigeria

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Abstract

The physical and mechanical properties of sandcrete produced with various blended proportions of sand grain sizes were investigated. River sand was sieved into three portions with distinct grain sizes. These were: sand containing only grains with diameters less than 1 mm (fine sand), 1-2 mm (medium sand) and 2-4 mm (coarse sand). Seven different combinations of grain sizes were proportioned by weight, with each combination containing 50% fine sand. Five cement/sand mix ratios, 1:4, 1:5, 1:6, 1:7 and 1:8, were used for moulding 150 × 150 × 150 mm sandcrete cubes. The results revealed that an increased proportion of coarse sand tended to increase the bulk density and compressive strength of sandcrete cubes after 28 days of curing. The grain size combination which gave the optimum compressive strength of sandcrete contained 50% fine sand, 10% medium sand and 40% coarse sand.

Keywords: Bulk density, Compressive strength, Grain size, Mix proportion, Sand, Sandcrete

1. Introduction

Sandcrete is a manufactured construction material produced by mixing cement, sand and water in a defined proportion. Sandcrete is different from concrete in terms of its material composition, since coarse aggregate is absent from the sandcrete mix [1]. Sandcrete is different from mortar because its slump is zero [1]. Sandcrete blocks are widely used for load bearing or non-load bearing walls in buildings in Nigeria and other West African countries. In Nigeria, the sizes and forms of sandcrete blocks include 450 × 225 × 225 mm hollow blocks, 450 × 150 × 225 mm hollow blocks, 450 × 113 × 225 mm hollow blocks, 450 × 125 × 225 mm solid blocks, and 450 × 100 × 225 mm solid blocks [1-2]. Several factors influence the physical and mechanical properties of sandcrete blocks. Among these properties are density and compressive strength. Density is a material property governed by its weight, which directly influences the dead load of the walls. Dry densities of blocks typically range from 500-2100 kg/m^3, with solid dense aggregate blocks being on the heavier side [3]. Compressive strength is a basic requirement of blocks except for non-load bearing blocks with thicknesses of less than 75 mm [3]. Generally, the strength of a block increases with its density. NIS 87:2004 [4] specifies compressive strength values of sandcrete blocks of various sizes and loading functions ranging from 1.85-3.45 N/mm^2. Investigations conducted by various researchers [2, 5-8] revealed that many sandcrete blocks commercially produced in different parts of Nigeria do not meet NIS 87:2004 [4] requirements for compressive strength. The quality of sandcrete blocks depends on many factors including aggregate size and grading, the quality of constituent materials, mix proportion, degree of compaction, method and duration of curing, and the form and size of the blocks [3, 9]. The importance of adequate quality control in production of sandcrete blocks cannot be over-emphasised.

The influence of aggregate size and grading on the mechanical properties of sandcrete has been previously studied. Omoregie and Alutu [10] evaluated the compressive strength of sandcrete blocks produced with sands from different sources in Benin City, Nigeria. They reported that when sands with higher silt contents are blended with those of lower silt contents, the compressive strength of the higher silt sand remarkably improves with comparatively few cost implications. Oyekan [11] investigated the effects of single-sized and mixed-sized coarse aggregates on the compressive strength of sandcrete blocks using 5, 10 and 15 mm aggregate sizes. The results showed that compressive strength increased when coarse aggregate was used as partial replacement for sand, and the optimum coarse aggregate content ranged from 25% for 5 mm aggregate to 35% for 15 mm aggregate.

This study aims at investigating the effects of proportioning sands with different grain sizes on the compressive strength and bulk density of sandcrete. The sand grain proportioning which gives the maximum compressive strength of sandcrete was determined for each sand/cement mix ratio.

*Corresponding author.
Email address: uchechi.eziefula@yahoo.com
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2. Experimental programme

2.1 Materials

The materials used in this study were ordinary Portland cement, river sand and tap water. Ordinary Portland cement of grade 42.5 was produced to the NIS 444-1:2003 [12] requirements and used as a binder in the production of sandcrete. A fine aggregate used in the experiment was river sand obtained from Otamiri in Owerri, Imo State, Nigeria. Sieve analysis of this river sand was initially conducted to determine the range of sand grain sizes. The grain size distribution curve from sieve analysis (Figure 1) showed that the grain sizes ranged from 5 mm to less than 0.1 mm. The physical properties of the river sand were determined and are presented in Table 1. Tap water was used for making fresh sandcrete and curing hardened sandcrete. The water was free from visible impurities and other deleterious materials.

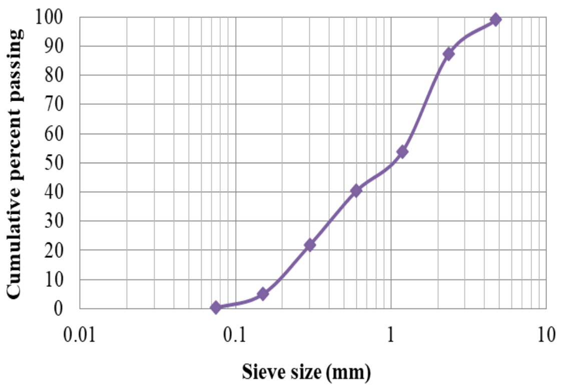

Figure 1 Grain size distribution of river sand

Table 1 Physical properties of river sand

Property	Value
Specific gravity	2.63
Fineness modulus	2.91
Bulk density	1,570 kg/m^3

2.2 Mix proportioning and preparation of samples

Sand was first manually sieved into three different sets of grain sizes using BS 410-1:2000 test sieves [13]. The BS EN 12620:2002 standard [14] puts the dividing line between fine aggregate and coarse aggregate at 4 mm. The first set of grain sizes were less than 1 mm ($X_1 \leq 1$ mm), the second ranged from 1-2 mm (1 mm $\leq X_2 \leq$ 2 mm), while the third were within the range of 2-4 mm (2 mm $\leq X_3 \leq$ 4 mm). The first, second and third sets of grain sizes represent fine, medium and coarse sand, respectively. These three sets of grain sizes were mixed in different proportions to give seven different combinations of sand grain sizes as shown in Table 2. Various combinations of sand grain sizes were proportioned by weight, and each grain size combination was given a proportion number. All the sand mix combinations contained 50% of the X_1 sand. X_2 and X_3 were varied.

Each sandcrete mix ratio was batched by weight. Five cement/sand mix ratios-1:4, 1:5, 1:6, 1:7 and 1:8-were used in the experimental programme. For each proportioned set of sand grain size, sandcrete cubes were produced for the various cement/sand mixture ratios. The amount of cement was also determined and the required weight of sand of each grain size was calculated for all mix ratios. The constituent materials were manually mixed on concrete pavement using a spade. Dry sand and cement were first mixed to a constant colour. Water was then added to the cement paste until workable sandcrete mixes of uniform colour were obtained. It was ensured that a limited quantity of water was added because excessive water will reduce the strength of the samples. It was also ensured that all the mixes had zero slump. The sandcrete was moulded in form of 150 × 150 × 150 mm cubes for each mix. Identification marks were made on each of the fresh sandcrete cubes. Twenty-one sandcrete cubes were cast for each mix ratio as shown in Table 3. Samples were left in their moulds for 24 hours before demoulding and curing. The samples were cured by sprinkling water on them twice a day for 28 days.

Table 2 Proportioning (by weight) for various sets of sand grain sizes

Proportion No.	X_1 (%)	X_2 (%)	X_3 (%)
C1	50	50	0
C2	50	40	10
C3	50	30	20
C4	50	25	25
C5	50	20	30
C6	50	10	40
C7	50	0	50

2.3 Testing of properties

The bulk density and compressive strength of the sandcrete cubes were determined for each sand mix combination and cement/sand mix ratio after 28 days of curing. Three cubes were made and tested for each selected grain size combination and sandcrete mix ratio. For each set, the masses of the three cubes were separately obtained prior to crushing. The density of the sandcrete cubes was determined in an air-dried state. The density of each cube was obtained by simply dividing its mass by its volume, and the mean value of the density was reported.

Compressive strength tests were done according to BS EN 12390-3:2009 [15] specifications. The result of the compressive strength for each mix was obtained by taking the mean values of three data points.

3. Results and discussion

3.1 Bulk density

The bulk densities of various grain size combinations and cement/sand mix ratios are given in Table 4. The densities of all the grain size combinations for the various mix ratios exceeded 2000 kg/m^3. It was observed that the maximum bulk density was obtained for C6 grain proportion using a 1:4 mix ratio whereas, the minimum bulk density was for C1 using a 1:6 mix ratio. The 1:4 mix ratio gave the highest bulk density for each grain proportion except for C4. Here the difference was marginal compared with 1:5 mix (2233 kg/m^3 and 2230 kg/m^3), and C7, where the bulk density for the 1:4 mix ratio was lower than the densities of other mix ratios, but nearly equal to the 1:8 mix (2171 kg/m^3 and 2170 kg/m^3). The highest bulk density for C7 was

Table 3 Mix proportions of sandcrete cubes

Mix ratio	Proportion No.	Cement (kg)	Sand (kg)		
			X_1 (kg)	X_2 (kg)	X_3 (kg)
1:4	C1	1	2	2	0
	C2	1	2	1.6	0.4
	C3	1	2	1.2	0.8
	C4	1	2	1	1
	C5	1	2	0.8	1.2
	C6	1	2	0.4	1.6
	C7	1	2	0	2
1:5	C1	1	2.5	2.5	0
	C2	1	2.5	2	0.5
	C3	1	2.5	1.5	1
	C4	1	2.5	1.25	1.25
	C5	1	2.5	1	1.5
	C6	1	2.5	0.5	2
	C7	1	2.5	0	2.5
1:6	C1	1	3	3	0
	C2	1	3	2.4	0.6
	C3	1	3	1.8	1.2
	C4	1	3	1.5	1.5
	C5	1	3	1.2	1.8
	C6	1	3	0.6	2.4
	C7	1	3	0	3
1:7	C1	1	3.5	3.5	0
	C2	1	3.5	2.8	0.7
	C3	1	3.5	2.1	1.4
	C4	1	3.5	1.75	1.75
	C5	1	3.5	1.4	2.1
	C6	1	3.5	0.7	2.8
	C7	1	3.5	0	3.5
1:8	C1	1	4	4	0
	C2	1	4	3.2	0.8
	C3	1	4	2.4	1.6
	C4	1	4	2	2
	C5	1	4	1.6	2.4
	C6	1	4	0.8	3.2
	C7	1	4	0	4

obtained for a 1:6 mix ratio. The 1:5 and 1:7 mix ratios attained their maximum bulk densities for the C7 proportion. The maximum bulk density of the 1:8 mix ratio was obtained for C5. The lowest bulk densities for all mix ratios were obtained for the C1 and C2 proportions, except for the 1:4 mix ratio where its lowest bulk density was obtained for C7. The low bulk densities obtained for C1 and C2 can be attributed to a low proportion of medium-sized sand since all the grain size combinations had equal amounts of fine sand. Similarly, the highest bulk densities for the various mix ratios were attained with either C6 or C7, except for the 1:8 mix, where the highest bulk density was obtained for C5. The C6 and C7 grain size combinations had the highest proportions of coarse sand which could be a reason for their high bulk densities. The bulk densities of the present investigation compared favourably with [16] who obtained 2228 kg/m^3 and 2244 kg/m^3 for mix ratios of 1:6 and 1:7.5, respectively.

The range of numerical values of bulk density for the different mix ratios was also calculated from Table 4 by subtracting the lowest value of each mix ratio from its highest value. The high values for these ranges suggested that the mix ratio was more influenced by changes in the proportions of sand grain sizes. The range for the 1:4 mix was 137 kg/m^3, 229 kg/m^3 for the 1:5 mix, 243 kg/m^3 for the 1:6 mix, 88 kg/m^3 for the 1:7 mix and 116 kg/m^3 for the 1:8 mix. It can be seen that the densities of the leaner mixes (i.e., 1:7 and 1:8 ratios) were least affected by changes in grain sizes, whereas the 1:6 mix was most influenced by combinations of the various grain sizes. The ranges in bulk densities of the various grain size combinations were as follows: C1 = 173 kg/m^3, C2 = 190 kg/m^3, C3 = 88 kg/m^3, C4 = 114 kg/m^3, C5 = 86 kg/m^3, C6 = 130 kg/m^3, and C7 = 133 kg/m^3. Grain size combinations that had nearly

Table 4 Bulk densities for various grain size combinations and cement/sand mix ratios

Grain proportion number	Bulk density (kg/m^3)				
	1:4	1:5	1:6	1:7	1:8
C1	2202	2084	2060	2169	2085
C2	2254	2064	2173	2194	2078
C3	2265	2244	2196	2177	2197
C4	2233	2230	2182	2199	2119
C5	2285	2199	2235	2236	2201
C6	2308	2283	2249	2229	2178
C7	2171	2293	2303	2257	2170

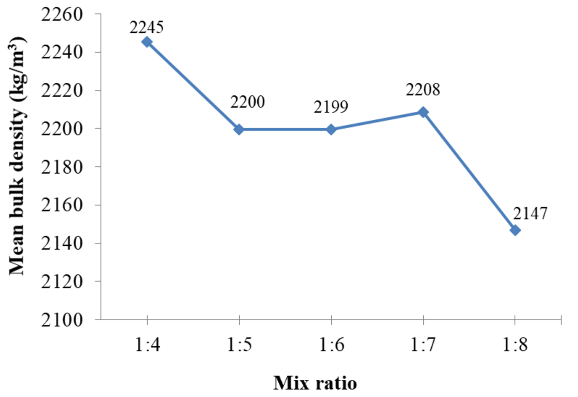

Figure 2 Mean bulk densities of sandcrete for various cement/sand mix ratios

Table 5 Mean bulk densities of medium/coarse sand proportion in all mix ratios

Rank	Proportion No.	Medium/ Coarse Ratio	Mean Density (kg/m^3)
1	C6	10:40	2249
2	C7	00:50	2239
3	C5	20:30	2231
4	C3	30:20	2216
5	C4	25:25	2193
6	C2	40:10	2153
7	C1	50:00	2120

equal amounts of medium sand and coarse sand (i.e., C3, C4 and C5) had the least variation in bulk densities. Those with a high content of medium sand and a low content of coarse sand (i.e., C1 and C2) showed the greatest variations. However, the variations in range of bulk densities for the various grain size combinations were insignificant when compared with the actual values of bulk densities.

The average bulk density was computed for the mix ratios by finding the mean bulk density of each mix ratio (Figure 2). The 1:4 mix ratio showed the maximum mean bulk density, whereas the 1:8 mix ratio gave the lowest mean bulk density. However, the relationship between mean bulk density and the cement/sand mix ratio was nonlinear. This could have been due to variations in the water/cement ratio of different mix ratios. Ranking the mean bulk densities for the various sand grain size proportions is presented in Table 5. It can be seen that mean bulk density of C6 was higher than that of C7. Also, the mean bulk density of all mix ratios using the C4 sand combination was lower than mean bulk density of both the C3 and C5 combinations. It is notable from Table 4 that C4 had a higher bulk density than C5 for the 1:5 mix ratio, and C4 also produced a bulk density higher than C3 for a 1:7 mix ratio. Again, these could be a result of variations in the water/cement ratio of various mix combinations.

3.2 Compressive strength

The compressive strength values of sandcrete cubes for the different combinations of grain sizes using the various mix ratios is presented in Table 6. A mix ratio of 1:4 gave the greatest compressive strength for all grain size combinations whereas a 1:8 mix had the least compressive

Table 6 Compressive strengths for various grain size combinations and cement/sand mix ratios

Grain proportion number	Compressive strength (N/mm^2)				
	1:4	1:5	1:6	1:7	1:8
C1	19.41	14.37	7.46	10.04	7.60
C2	25.33	11.85	8.62	9.97	6.75
C3	25.25	16.04	16.59	14.22	10.67
C4	27.56	17.78	15.41	11.56	6.32
C5	27.41	15.18	16.00	11.71	8.49
C6	29.33	25.71	17.63	12.89	7.70
C7	24.23	20.34	17.05	14.59	8.62

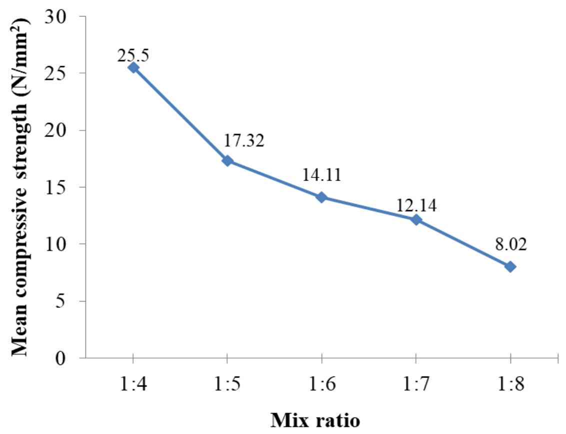

Figure 3 Mean compressive strengths of sandcrete for various cement/sand mix ratios

strength except for the C1 grain size combination, where a 1:6 ratio gave the lowest strength. All the mixes showed compressive strengths greater than 6 N/mm^2. Ettu et al. [17] obtained a compressive strength of 9.60 N/mm^2 for a 1:6 mix ratio using a constant water/cement ratio of 0.6. Numerical values of compressive strength of the 1:6 mix ratio in the present investigation varied from 7.46 N/mm^2 (C1) to 17.63 N/mm^2 (C6).

The range of compressive strengths for each mix can be obtained from Table 6. The range in values of compressive strength for C1, C2, C3, C4, C5, C6 and C7 are 11.95, 18.58, 14.58, 21.24, 18.94, 21.63 and 15.61 N/mm^2, respectively. A small range of these values within a group means that the grain size combination had a relatively minimal effect on changes in the cement/sand mix ratio. The compressive strengths of the C1 mixes were least affected by changes in the sand/cement mix, whereas the strength of C6 samples were most affected.

Figure 3 shows the mean compressive strength of each mix ratio. The relationship between the mean compressive strength and mix ratio was linear. The 1:4 mix ratio showed the maximum mean compressive strength while the 1:8 mix ratio gave the lowest mean compressive strength. Richer mixes generally produced higher compressive strengths in sandcrete. The greatest difference in mean strength was observed for the 1:4 and 1:5 mixes. However, the difference between the 1:7 and 1:8 mix ratio was higher than the mean strength differences between the 1:6 and 1:7, and 1:5 and 1:6 mix ratios.

Table 7 Ranking of compressive strengths of medium/coarse sand proportions

Rank	Compressive Strength (N/mm^2)				
	1:4	1:5	1:6	1:7	1:8
1	C6 (29.33)	C6 (25.71)	C6 (17.63)	C7 (14.59)	C3 (10.67)
2	C4 (27.56)	C7 (20.34)	C7 (17.05)	C3 (14.22)	C7 (8.62)
3	C5 (27.41)	C4 (17.78)	C3 (16.59)	C6 (12.89)	C5 (8.49)
4	C2 (25.33)	C3 (16.04)	C5 (16.00)	C5 (11.71)	C6 (7.70)
5	C3 (25.25)	C5 (15.18)	C4 (15.41)	C4 (11.56)	C1 (7.60)
6	C7 (24.23)	C1 (14.37)	C2 (8.62)	C1 (10.04)	C2 (6.75)
7	C1 (19.41)	C2 (11.85)	C1 (7.46)	C2 (9.97)	C4 (6.32)

Table 8 Mean compressive strengths of medium/coarse sand proportion in all mix ratios

Rank	Proportion No.	Medium/Coarse Ratio	Mean Strength (N/mm^2)
1	C6	10:40	18.65
2	C7	00:50	16.97
3	C3	30:20	16.55
4	C5	20:30	15.76
5	C4	25:25	15.73
6	C2	40:10	12.50
7	C1	50:00	11.78

It can be observed in Table 6 that the C6 and C7 sand combinations generally showed greater compressive strengths than other combinations of sand sizes. In the richer mix ratios (i.e., 1:4, 1:5 and 1:6), the greatest compressive strength was observed for C6. The greater compressive strength of C6 and C7 can be attributed to the presence of larger quantities of coarse sand. However, C3 showed relatively high values of compressive strength in the leaner mixes (i.e., 1:7 and 1:8), and the C3 samples showed a maximum compressive strength in the 1:8 mix. Table 7 presents a comparative ranking of grain proportions for each mix ratio based on their compressive strengths. C1 and C2 generally showed comparatively lower values of compressive strength for all mix ratios. C1 gave the lowest compressive strength for the 1:4 and 1:6 mixes, whereas C2 gave the lowest strength for the 1:5 and 1:7 mixes. This can be attributed to a higher proportion of medium-sized grains in the blended sand in relation to the coarse grains. C4 produced comparatively large compressive strengths for the richer cement/sand mixes, but gave lower values for lean mix ratios. The greatest compressive strengths for the leaner mixes were attained by the C3 and C7 samples. The average compressive strengths of mix ratios is presented in Table 6. The rank and average compressive strength of each grain size combination are presented in Table 8. The results in Table 8 correlate well with the mean bulk density results in Table 5 in terms of ranking of the grain proportions. The only exceptions are seen for C3 and C5, whose ranks of 3 and 4 are switched for bulk density and compressive strength. Overall, the C6 combination gave the optimal compressive strength of sandcrete after curing for 28 days.

4. Conclusions and recommendations

The effects of proportioning sand of different grain sizes on the 28-day bulk density and 28-day compressive strength of sandcrete were investigated in this study. Seven different combinations of sand grain sizes were used in five sandcrete mix ratios. First, coarse sand tended to increase the bulk density of sandcrete. Sandcrete with a high proportion of coarse sand generally had higher values of bulk density. The lowest bulk densities for all mix ratios were obtained for sand combinations where the quantity of coarse sand did not exceed 10%, except for the 1:4 mix, which lacked medium-sized sand. Similarly, the highest bulk densities were attained in C6 and C7 samples for the various mix ratios, except for the 1:8 mix ratio.

Second, the compressive strength of sandcrete tended to increase with an increased proportion of coarse grain sand. Grain size combinations of sand, where the maximum quantity of coarse sand was at least 40%, generally resulted in higher values of compressive strength. Combinations where the maximum amount of medium grain sand was 40% had the lowest compressive strengths. The maximum compressive strength of sandcrete for 1:4, 1:5 and 1:6 mix ratios all contained 50% fine sand (grain sizes less than 1 mm), 10% medium sand (1-2 mm grain size) and 40% coarse sand (2-4 mm grain size). The grain size combination that did not contain any medium sand content gave a maximum compressive strength for the 1:7 mix. Sandcrete with 50% fine sand, 30% medium sand and 20% coarse sand attained a maximum strength in the 1:8 mix ratio. The grain size combination that resulted in an optimum compressive strength of sandcrete contained 50% fine sand, 10% medium sand and 40% coarse sand.

The authors suggest that future work should consider keeping either the percentage of medium or coarse grain sand constant while changing the proportions of the other sand sizes. Additionally, future studies should specify the amount of water used in the production of sandcrete cubes and vary the water/cement ratio to determine the optimum water/cement ratio. Other properties of sandcrete such as splitting tensile strength, flexural strength, modulus of elasticity, thermal conductivity, fire resistance and water absorption should be investigated. Attempts should also be made to study the effects of varying of the sand grain sizes on the properties of sandcrete at later curing ages such as 90, 180 and 365 days.

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