Original Article

Physico-mechanical behaviour of sandcrete block masonry units

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ABSTRACT This paper is laboratory test-focused, and reports the results of investigation of the strength and density of sandcrete blocks based on a 1:4 model of the prototype. Two hundred and seventy-one sandcrete block models from four mixed proportions, namely 1:4, 1:6, 1:8 and 1:10, were tested at the ages of 7, 14, 21 and 28 days, with various water–cement ratios. The result revealed the practical correspondence of test values and trends for test values and variational trends for BS 2028 reference characteristics of strength and density, which provide concrete evidence of reproducibility of the prototype physico-mechanical behaviour under load by its one-quarter structural model. The possibility of application of scaled-down wall models containing model block units will reduce requirements of laboratory space and loading equipment, thus widening the scope of research on the structural resistance mechanism of sandcrete blockwalls.

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INTRODUCTION

The popularity of sandcrete blocks and their extensive application as walling material in Nigeria and other developing countries cannot be overemphasised. Sandcrete blocks, when properly produced, meet BS 2028 (1968) recommendations for density and compressive strength of structural masonry.

Sandcrete blockwalls are usually not designed to support loads other than their own weight. However, one of the earliest warning signs of failure is often manifested by the formation of serious critical structural cracks (Figure 1) long before the actual event. Recent structural collapses in Nigeria and elsewhere have raised serious concerns for more in-depth and intensified study on the mechanism of resistance of all components of the structure, as reported by Wenapere (2008), Gajanan *et al* (1983), Adisa (1997) and Ogar (1997). However, while significant research effort has been devoted to steel and reinforced concrete, concrete framework, concrete masonry blocks and blockwalls, there have been few studies on sandcrete, and these have

Figure 1: A typical sandcrete wall failure in Yenagoo, Nigeria.

been limited to block units only. There are very few recorded tests on sandcrete blockwalls.

Structural cracks may be associated with differential foundation movement or other movements leading to the transfer of load from frame to blockwall, among others (Figure 2). Thus, the blockwall may be expected to possess enough strength to support its own loads, the effects of additional environmental and accidental loads, and any loads transferred from the structural frame. In addition, the blockwall should provide some reasonable in-fill restraint to the structural frame.

Current views on the strength deformations and failure mechanism of concrete masonry under static and dynamic loads are presented in the recent studies by Abrams (1996, 1997), Andam (2002a, b), Page (1981), Paulson *et al* (1990) and Stroven (2002), among others. The problems of frame-in-fill interaction are addressed in the investigative studies by Ephraim *et al* (1990), Liauw *et al* (1983) and Madan *et al* (1997), among others. The few important studies that have attempted to address the connection of mixed composition and compactive effort on the strength and economy of sandcrete masonry include those by Wenapere (2003), Andam (2002a, b), Chandhari and Gumel (2000) and Uzomaka (1977), among others.

The laboratory investigation of blockwall is highly limited by the sheer size and the loading equipment requirements, and due to this, a model study is perhaps the more realistic way forward, and is also provided for in Act 318 (1) and BS. 8110 (1997). In fact, most masonry models investigated have been in the form of scaled-down walls built of prototype concrete or brick block units. It is obvious that the use of reduced-scale blocks will decrease the laboratory space requirement and lighten the loading equipment required for testing. This would invariably increase the level of research, especially in situations where sophisticated and heavy equipment is not available.

Figure 2: A typical commercial bank building with visible sandcrete wall cracks in Yenagoa, Nigeria.

Thus, the main objective of this research was to investigate and establish the adequacy of a one-quarter scale structured model of hollow-block sandcrete masonry in order to reproduce the physical and structural characteristics of the prototype masonry units and blockwall as a function of mixed proportion and applied compressive loading. This will become a tool for sandcrete building designers and engineers aiming to diagnose likely failure modes in the blockwalls.

PHYSICAL MODELLING AND TESTING

Physical modelling and testing included the laboratory fabrication of one-quarter hollow sandcrete blocks in steel moulds, and the curing and testing in the compression machine of the test blocks. The model block dimensions were 112.5×37.5×56.25 mm, being $\frac{1}{4}$ representations of the prototype sizes of 450×150×225 mm. The compressive strength of the block was determined for four mixed proportions, 1:4, 1:6, 1:8 and 1:10, at the ages of 7, 14, 21 and 28 days. Other related tests included sieve analysis of sand used and determination of densities. All the experimental works were carried out in accordance with BS 5628(1978) and 1377-2(1990). A total of 271 sandcrete blocks were tested in this research: 80 blocks at the age of 7 days, 63 blocks at 14 days and 64 blocks each at 21 days, all in accordance with the standard provisions of BS 5628 (1978). The testing arrangements are shown in Figure 3.

ANALYSIS AND DISCUSSION OF RESULTS

This study is focused on the verification of the reproducibility of prototype engineering properties of sandcrete block by its $\frac{1}{4}$ scale model. The results are analysed and discussed in the relevant section that follows.

Comparisons are carried out in terms of density and compressive strength of prototype and model sandcrete blocks.

Figure 3: Testing arrangement of $\frac{1}{4}$ scale sandcrete blockwalls.

EFFECT OF WATER/CEMENT RATIO ON THE COMPRESSIVE STRENGTH OF SANDCRETE BLOCKS

Experimental values of compressive strength of model and prototype sandcrete blocks as a function of mixed proportion and the water–cement ratio are shown in Table 1 and plotted in Figure 4.

From the table and plots, it can be seen that sandcrete blocks with mix 1:4 generated the highest strength, followed by 1:6, 1:8 and 1:10, in that order. The compressive strength of sandcrete block units in model and prototype rose with increase in the water–cement ratio, until it attains a maximum value at an optimum value of about 0.5 for all mixes tested. The maximum value at 28 days constituted 7.60, 6.85, 4.47 and 3.80 N/mm² for prototype 1:4, 1:6, 1:8 and 1:10 blocks, respectively. The corresponding values for the model blocks were 7.46, 6.50, 4.30 and 3.65 N/mm². The predicted values, however, showed marked variation in their rate of growth with age of curing, as shown in Table 2.

Variation of compressive strength of sandcrete block with age

Table 2 shows the laboratory results of compressive strength and densities of prototype and model sandcrete blocks as a function of duration of wet curing and mix composition at the optimal water–cement ratio of 0.5 W/C. The functional dependence of compressive strength of sandcrete prototype blocks at 0.5 W/C on the duration of wet curing is graphically plotted in Figure 5. The comparative plots of model block and prototype compressive strength as function of age are also shown in Figure 5.

From Figure 5, the practical correspondence of the prototype and model compressive strength variation can be confirmed.

The compressive strength of sandcrete blocks increased with longer wet curing durations for all of the mixes tested, as expected. A water–cement ratio (w/c) of 0.5 (Table 1). The strength at ages 7, 14 and 21 days constituted, respectively, 43, 75 and 92 per cent of the 28-day strength, which were practically the same for the prototype and model sandcrete blocks. This trend is also in close agreement with trends reported from the experimental studies by Uzomaka (1977).

Table 1: Model and prototype sandcrete block compressive strength at 28 days

W/C	Compressive strengths (N/mm ²)							
	1:10		1:8		1:6		1:4	
	Prototype	Model	Prototype	Model	Prototype	Model	Prototype	Model
0.3	2.40	2.50	4.08	3.20	5.40	5.00	6.10	5.90
0.4	3.00	3.10	4.39	4.10	5.58	5.30	6.23	6.00
0.5	3.80	3.65	4.47	4.30	6.85	6.50	7.60	7.46
0.6	3.60	3.60	4.24	4.09	6.41	6.30	7.00	6.50
0.7	3.20	3.10	4.21	3.95	5.89	5.40	6.54	6.30

Figure 4: Comparative plots of prototype and model compressive strengths at 28 days.**Table 2:** Compressive strength of sandcrete block units at different ages (W/C=0.5)

S/No.	Age (Days)	Model f_{cu} (N/mm ²)				Prototype f_{cu} (N/mm ²)			
		1:4	1:6	1:8	1:10	1:4	1:6	1:8	1:10
1	7	3.22	2.85	2.10	0.95	3.20	2.95	2.08	0.95
2	14	5.56	4.90	3.00	2.00	5.60	4.91	3.04	2.66
3	21	6.85	6.24	3.80	3.15	7.10	6.40	3.86	3.20
4	28	7.46	6.50	4.30	3.65	7.60	6.85	4.47	3.80

Density of sandcrete blocks

The test values of densities for prototype and model blocks are recorded in Table 4. From this table, it can be seen that there is a practical correspondence in the densities of the model sandcrete blocks in all the mixes and water–cement ratios considered. As indicated in the reports by Uzomaka (1977), the densities and strength as a function of the water–cement ratio are in close agreement with those of the prototype blocks.

Figure 5: Comparative plots of compressive strength of prototype and model sandcrete blocks with age at W/C=0.5.

Table 3: Density variation with age as it affects the compressive strength at 0.5 W/C (Model)

S/No.	Identification mark	Age in days	Density of specimen (kN/m ³)	Compressive stress (N/mm ²)
1	Model block MB 5-4	7	19.10	3.22
	Prototype Block PB 5-4	7	19.50	3.20
2	Model block MB 5-6	7	18.40	2.85
	Prototype Block PB 5-6	7	19.40	2.95
3	Model block MB 5-8	7	19.10	2.10
	Prototype Block PB 5-8	7	19.50	2.08
4	Model block MB 5-10	7	18.60	0.95
	Prototype Block PB 5-10	7	19.50	0.95
5	Model block MB 5-4	14	18.60	5.56
	Prototype Block PB 5-4	14	18.90	5.60
6	Model block MB 5-6	14	18.60	4.90
	Prototype Block PB 5-6	14	18.90	4.91
7	Model block MB 5-8	14	18.60	3.00
	Prototype Block PB 5-8	14	18.90	3.04
8	Model block MB 5-10	14	18.60	2.00
	Prototype Block PB 5-10	14	18.90	2.66
9	Model block MB 5-4	21	18.40	6.85
	Prototype Block PB 5-4	21	18.90	7.10
10	Model block MB 5-6	21	18.40	6.24
	Prototype Block PB 5-6	21	18.90	6.40
11	Model block MB 5-8	21	18.90	3.80
	Prototype Block PB 5-8	21	18.90	3.86
12	Model block MB 5-10	21	18.20	3.15
	Prototype Block PB 5-10	21	18.90	3.20
13	Model block MB 5-4	28	18.60	7.46
	Prototype Block PB 5-4	28	19.10	7.60

Table 3: Continued

<i>S/No.</i>	<i>Identification mark</i>	<i>Age in days</i>	<i>Density of specimen (kN/m³)</i>	<i>Compressive stress (N/mm²)</i>
14	Model block MB 5-6	28	18.40	6.50
	Prototype Block PB 5-6	28	19.10	6.85
15	Model block MB 5-8	28	18.40	4.30
	Prototype Block PB 5-8	28	19.10	4.47
16	Model block MB 5-10	28	18.60	3.65
	Prototype Block PB 5-10	28	18.90	3.80

Table 4: Densities of prototype and model sandcrete blocks at 28 days

<i>S/No.</i>	<i>W/C</i>	<i>Density (kN/m³)</i>			
		<i>Mix 1:4</i>	<i>Mix 1:6</i>	<i>Mix 1:8</i>	<i>Mix 1:10</i>
1	0.3				
	Prototype	19.10	19.10	18.90	18.90
	Model	18.60	18.60	18.60	18.20
2	0.4				
	Prototype	18.90	19.10	19.10	19.10
	Model	18.60	18.60	18.20	18.60
3	0.5				
	Prototype	19.10	19.10	19.10	18.60
	Model	18.60	18.40	18.40	18.60
4	0.6				
	Prototype	18.90	19.10	18.90	19.10
	Model	18.20	18.40	18.40	18.20
5	0.7				
	Prototype	19.20	19.10	19.20	19.10
	Model	18.20	18.20	18.40	18.40

CONCLUSION

The comparative analysis of laboratory test results of the influence of mixed proportions, water–cement ratio and age on the strength of sandcrete blocks for prototype and model has been undertaken in this research with a view to confirm the applicability of code recommendation on modelling to sandcrete masonry structures. The results reveal the practical correspondence of test values and trends for major characteristics of strength and density, which provides concrete evidence of reproducibility of prototype sandcrete physico-mechanical behaviour under load by its ¼ scale model.

More particularly, the results of laboratory tests and analysis of the effects of mix and water–cement ratios on the physical and mechanical properties of sandcrete blocks in prototype and ¼ scale models have shown that

1. The density of sandcrete masonry block units showed no marked variation with respect to mixed-ratio water content or ages of wet curing. The maximum value ranged from 18.9 to 19.50 kN/m³ for 1:4, 1:6, 1:8 and 1:10 mixes, respectively. The results from the model were found to be representative of and in close agreement with those of the prototype block units.

2. The compressive strength of sandcrete masonry block units in model and prototype rose with the increase in the water–cement ratio, attaining a maximum value at an optimum value of about 0.5 for all mixes tested. The maximum value at 28 days constituted 3.8, 4.47, 6.85 and 7.60 N/mm² for prototype 1:10, 1:8, 1:6 and 1:4 blocks, respectively. The corresponding values for the model blocks were 3.65, 4.3, 6.50 and 7.46 N/mm². The predicted values of strength as a function of the water–cement ratio are in close agreement with those of the prototype blocks.
3. The compressive strength of sandcrete blocks increased with age of wet curing for all mixes tested at the water–cement ratio of 0.5, as expected. The strength at ages 7, 14 and 21 days constituted, respectively, 43, 75 and 92 per cent of the 28-day strength.

RECOMMENDATIONS

The above conclusions have substantiated the applicability of the Code of Practice recommendation in respect of use of models for analysis and design, with particular reference to the 1/4 scale model. The unique contribution of this research is the extension of the codes recommendation to sandcrete masonry structures, thus opening up the potential, scope and opportunities for research in sandcrete masonry structures, especially in developing nations and elsewhere where sophisticated and heavy equipment are not available for prototype scale tests. To this end, model tests are recommended to study the strength, durability and failure mechanisms of the masonry structures in other stressed states including flexure, shear, dynamic loading and their combinations, such that the national concern over building collapses will ultimately receive a practical solution.

REFERENCES

- Abrams, D.P. (1997) Response of unreinforced masonry building. *Journal of Earthquake Engineering* 1(1): 257–273.
- Abrams, D.P., Angel, R. and Uzarski, J. (1996) Out-of-plane strength of unreinforced masonry infill panels. *Earthquake Spectra, Journal of Earthquake Engineering Research Institute* 12(4): 825–844.
- Adisa, A. (1997) Proceedings of the 8th conference of the National Council on Housing, Federal Ministry of Works and Housing, Calabar, Nigeria, pp. 12–14.
- Andam, K.A. (2002a) *Compressive Strength of Commercial Sandcrete Blocks*. Proceedings of the 4th International Conference on Structural Engineering Analysis and Modelling (SEAM 4); University of Science and Technology, Kumasi, Ghana, Vol. 1, p. 282.
- Andam, K.A. (2002b) *Enhancing the Compressive Strength of Concrete Blocks with Single and Mixed Coarse Aggregates*. Proceedings of the 5th International Conference on Structural Engineering Analysis and Modelling (SEAM 5); University of Science and Technology, Kumasi, Ghana, Vol. 1, pp. 75–78.
- British Standard Institution. (1978) Structural Use of Masonry. Part 1. Unreinforced Masonry. London: BSI. BS 5628.
- BS 8110 British Standard Institution. (1997) Structural Use of Concrete. London: BSI.
- BS 1377-2 British Standard Institution. (1990) Methods of Test for Soils for Civil Engineering Purposes. Classification Tests. London: BSI.
- BS 5628 British Standard Institution. (1978) Specification for Precast Concrete. London: BSI.
- Chandhari, K.P.R. and Gumel, H.A. (2000) Sandcrete blocks for buildings: A detail study on mix compositions, strength and their cost. *Journal of Nigerian Society of Engineers* 38(1): 5–15.
- Ephraim, M.E., Chinwah, J.G and Orlu, I.D (1990) *Mechanism Approach to Composite Frame and Infill*. Proceedings of the Second International Conference on Structural Engineering Analysis and Modelling (SEAM 2); University of Science and Technology, Kumasi, Ghana, Vol. 1, pp. 13–26.
- Gajanan, M.S., Harris, H.G., White, R.N. and Mirza, S. (1983) *Structural Modeling and Experimental Techniques*. Englewood Cliffs, NJ: Prentice-Hall.
- Liauw, T.C. and Kwan, K.H. (1983) Plastic theory of infilled frames with finite interface shear strength. *Proceedings of the Institution of Civil Engineers* 75(Part 2): 707–723.

- Madan, A., Reinhorn, A.M., Mander, J., Mander, J. and Valles, R. (1997) Modeling of masonry infill panels for structural analysis. *ASCE Journal of Structural Engineering* 123(10): 1295–1302.
- Ogar, P.A.M. (1997) Proceedings of the 8th conference of the National Council on Works, Federal Ministry of Works and Housing, Kwara State, Nigeria, pp. 13–14.
- Page, A.W. (1981) The biaxial compressive strength of brick masonry. *Proceedings of the Institution of Civil Engineers* 71(Part 2): 893–906.
- Paulson, T.J. and Abrams, D.P. (1990) Correlation between static and dynamic response of model masonry structures. *Earthquake Spectra, Journal of the Earthquake Engineering Research Institute* 6(3): 573–590.
- Stroven, P. (2002) *Damage in Compressed Masonry Due to Stress Release*. Proceedings of the Fourth International Conference on Structural Engineering Analysis and Modelling (SEAM 4); University of Science and Technology, Kumasi, Ghana, Vol. 1, pp. 162–171.
- Uzomaka, O.J. (1977) An appraisal of methods of testing some physical properties of sandcrete blocks. *Proceedings of the Institution of Civil Engineers* 63(Part 2): 625–639.
- Wenapere, A.D. (2003) Structural modelling of compressive strength of sandcrete blockwalls. M Tech thesis, Rivers State University of Science and Technology, Port Harcourt.
- Wenapere, A.D. (2008) Finite element modeling of sandcrete infills under static vertical loading. a PhD – Structural Engineering Seminar Paper in Rivers State University of Science & Technology, Port Harcourt, Nigeria.