Scientific African 7 (2020) e00263

Contents lists available at ScienceDirect

Scientific African

journal homepage: www.elsevier.com/locate/sciaf

The use of red earth, lateritic soils and quarry dust as an alternative building material in sandcrete block

Banjo A. Akinyemi[a,*], Alhassan Elijah[a], Aladegboye Oluwasegun[b], Denen T. Akpenpuun[c], Owolaja Glory[b]

[a] Department of Agricultural and Biosystems Engineering, Landmark University, P.M.B. 1001 Omuaran, Nigeria
[b] Department of Civil Engineering, University of Ilorin, Kwara State, Nigeria
[c] Department of Agricultural and Biosystems Engineering, University of Ilorin, Kwara State, Nigeria

ARTICLE INFO

Article history:
Received 11 July 2018
Revised 9 December 2019
Accepted 13 January 2020

Editor: Dr. B. Gyampoh

Keywords:
Earth
Compressive
Laterite
Quarry
Blocks
Materials

ABSTRACT

This study investigated the prospect of utilising red earth, quarry dust and laterite as alternative materials to river sand in the production of sandcrete blocks. Compressive strength test was performed on the samples at 7, 14, 21 and 28 curing days in the laboratory. The effect of curing on strength improvement was also studied. Using one way analysis of variance (ANOVA) and Tukey analysis, the results showed that quarry dust and lateritic soil performed relatively better in comparison with the traditional river sand used in sandcrete blocks production. Also there was progressive improvement of the compressive strength of the tested materials over the period of curing regime adopted for the study. Red earth and quarry dusts showed good prospect as alternative to the use of river sand in sandcrete block production for developing nations.

© 2020 The Authors. Published by Elsevier B.V. on behalf of African Institute of Mathematical Sciences / Next Einstein Initiative.
This is an open access article under the CC BY license.
(http://creativecommons.org/licenses/by/4.0/)

Introduction

In order to provide a sustainable house, most of the people in developing nations would prefer to build low cost housing with locally available materials. Low cost housing is a new concept of technique which help in reducing the cost of construction through the use of locally available materials along with improved skills and technology without sacrificing the strength, performance, and life of the structure [8,5]. The impediments to solving the housing problem are scarcity and high cost of building materials. Ideally, low-cost housing must rely on locally available raw materials. Furthermore, such materials must be abundantly available and be renewable in nature. Due to these various reasons, the investigations of alternative materials for the construction of low cost housing have been the focus of many studies in many developing countries [6,7,19,25]. Awoyera et al. [2] investigated the mechanical strength of lateritic soil and ceramic waste with high strength value reported for higher percentage of lateritic soil in the mortars tested. In the same vein other concluded researches on laterite as a building material include Bal et al. [3], Mbumbia and de Wilmars [20], Bal et al. [4] and Oyelami and Van [24]. In quarrying activities, the rock has to be crushed into various sizes and during this process a large cloud

* Corresponding author.
E-mail address: bantonbows@gmail.com (B.A. Akinyemi).

https://doi.org/10.1016/j.sciaf.2020.e00263
2468-2276/© 2020 The Authors. Published by Elsevier B.V. on behalf of African Institute of Mathematical Sciences / Next Einstein Initiative. This is an open access article under the CC BY license. (http://creativecommons.org/licenses/by/4.0/)

Table 1
Experimental mix.

S/N	Types of blocks	Mix ratio	Number of blocks tested/curing days				Replicate
			7	14	21	28	
1	Cement + River Sand (CRS)	1:6	3	3	3	3	12
2	Cement + Red Earth (CRE)	1:6	3	3	3	3	12
3	Cement + Laterite (CLT)	1:6	3	3	3	3	12
4	Cement + Red Earth + River Sand + Laterite (RLR)	1:2:2:2	3	3	3	3	12
5	Cement + Quarry Dust (CQD)	1:6	3	3	3	3	12

Fig. 1. Red earth.

of dust is generated which eventually settle down in a heap, this is called quarry dust and it is usually termed as waste in most quarry sites. Quarry dust could be used for building purposes and this will reduce the cost of construction and volume of construction materials will also be reduced [26]. Galetakis et al. [10] produced self-flowing castable building elements using quarry dust, Li et al. [17] also produced concrete samples by replacing fly ash with granite dust in different proportions, the result showed an improved compressive strength at 20% replacement and Thomas and Harilal [28] used quarry dust and fly ash to prepare concrete using cold bonding process and a substantial improvement in the tested mechanical properties were reported. There is however little or no reported research on the use of red earth as construction material except for some similarities pointed out between it and clay. Red earth also called *Murrum* or *Moorum* is formed in the tropics through the weathering process that favours the formation of iron, aluminium, manganese and titanium oxides. Iron and aluminium oxides are prominent in red earth, and with the seasonal fluctuation of the water table, these oxides result in the reddish-brown colour of the soil. Red earth is widely distributed throughout the world in the regions with high rainfall, but especially in the inter-tropical regions of Africa, where they generally occur just below the surface of grasslands or forest clearings [16]. Subbarao and Rao [27] produced building blocks and structural pavement material from mixing red earth with some quantities of cement. The red earth material would provide a good alternative to river sand which is a major constituent of sandcrete blocks made in most developing nations. The use of sandcrete blocks dates back to the colonial era in the late nineteenth and early twentieth century [14]. Despite the introduction of new building materials, the use of sandcrete blocks in the construction industry have gained wide patronage; sandcrete blocks are widely used as walling units in building, construction of drainages and other masonry works. The world-wide consumption of sand as fine aggregate in sandcrete block production is very high, and several developing countries have encountered some strain in the supply of natural sand in order to meet the increasing needs of infrastructural development in recent years. A situation that is responsible for increase in the price of sand, and the cost of sandcrete blocks [18]. Expensive and scarcity of river sand which is one of the constituent material used in the production of conventional concrete was reported recently in India [12]. Therefore in order to overcome the stress and demand for river sand, red earth soil, lateritic soil and quarry dust have been identified and evaluated to provide an alternative in sandcrete block production.

Experimental work

Materials

River sand and lateritic soils were sourced locally around the Landmark University premise with a geographical position of 8.1239° N, 5.0834° E. Red earth soil (Fig. 1) was gotten at a location around a hilly terrain within the University premise while quarry dust (Fig. 2) was obtained from a quarry site within the township of Omuaran at a location of 8.1402° N, 5.0963° E. Ordinary Portland cement that conforms to ASTM Type 1 was purchased in a building materials retail store and

Table 2
Soil classification and specific gravity (S.G) of soil samples.

Material	C_u	C_c	USCS	S.G
River sand	4	0.87	Poorly graded	2.75
Quarry dust	12.5	0.68	Poorly graded	2.5
Laterite	11	7.36	Poorly graded	2
Red earth	14	1.14	Well graded	2.1

Fig. 2. Quarry dust.

potable water from the Geotechnical Laboratory was also used. The experimental design in Table 1 was adopted for the production of the sample blocks.

Sieve analysis and specific gravity

Table 2 shows the soil classification and specific gravity (S.G) of the materials used.

The equations below were used in the sieve analysis

$$\text{Cu} = \frac{D_{60}}{D_{10}} \tag{1}$$

$$\text{Cc} = \frac{(D_{30})^2}{(D_{60}\ x\ D_{10})} \tag{2}$$

where Cu is the coefficient of uniformity, D_{60} is grain diameter in mm (60% passing on the curve), D_{10} is grain diameter in mm (10% passing on the curve), D_{30} is grain diameter in mm (30% passing on the curve) and Cc is coefficient of curvature. From the graphs shown in Fig. 3, the values for D_{10}, D_{30} and D_{60} were obtained which were used to calculate coefficient of uniformity and coefficient of curvature. Using the Unified Soil Classification System (USCS) to classify these soil samples, the river sand is not a well graded soil but a poorly graded soil also its fines are silty. Quarry dust is poorly graded as well, laterite is poorly graded and red earth is well graded.

Methods

The sieve analysis test was used to determine the distribution of the coarser, larger-sized particles and it is widely used in the classification of soil. This analysis was carried out on all the materials that were used except for cement. Specific gravity test was also conducted to determine the specific gravity of the soil fraction passing the 75 µm sieve by density bottle. For the compressive strength test, moulds of 225 × 225 × 450 mm of 40% void were used to produce compressive test samples [9] and a total of 60 samples were produced altogether. The mortar was mixed manually in the ratio of 1:6 (one part cement and six part sand) ratio as shown in Table 1 and water cement ratio of 0.5 was kept constant for the entire samples produced. The moulds were oiled with waste engine oil to ensure easy de-moulding process, the mortar was poured into the mould and compacted electrically using a rammer. They were allowed to cure naturally in the laboratory at 24 °C for 7, 14, 21 and 28 days before the tests were conducted.

Each block was tested at a loading rate of 15 mm/min using a 2000KN capacity compressive testing machine at the Department of Civil Engineering Laboratory, Landmark University, Nigeria. No effort was made to produce frictionless ends, in order to simulate as closely as possible the actual procedure in practice. The obtained compressive strength results were compared with the Federal Republic of Nigeria, National Building Code 35 which is 1.75 MPa to determine if they conform to the standard.

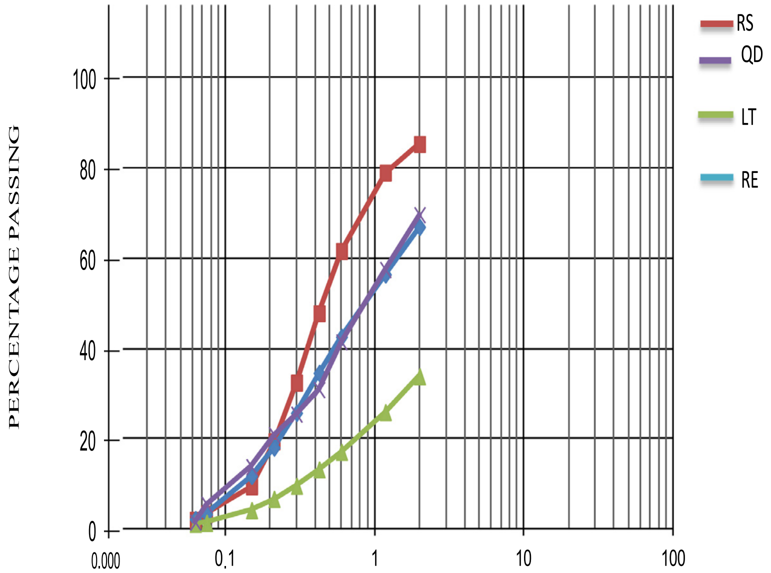

Fig. 3. Grain size analysis for red earth (RS – River sand, QD – Quarry dust, LT– Laterite and RE – Red earth).

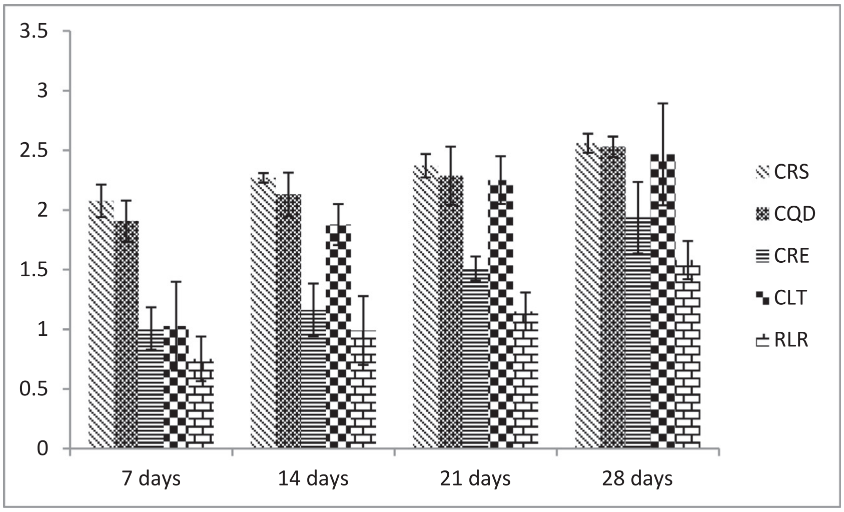

Fig. 4. Compressive strength of bricks (CRS- cement+river sand, CQD- cement+quarry dust, CRE-cement+red earth, CLT-cement+laterite and RLR-river sand+laterite+red earth).

Results and discussions

Compressive strength

Compressive strength at 7 days

After curing the blocks for 7 days the blocks made with cement and river sand had the highest average compressive strength of 2.08 N/mm^2 compared with the rest (Fig. 4), the difference between the average compressive strength of the blocks made with cement and quarry dust which is 1.91 N/mm^2 is not so much. While those made with the mixture of red earth, laterite and river sand alone has the lowest average compressive strength (0.75 N/mm^2). The *p*-value corresponding to F-statistics of One Way ANOVA is lower than 0.01 which suggests that one or more of the sample blocks are significantly different. Therefore to further compare the strength of the respective blocks, Tukey HSD test with $Q_{statistic}$ was used based on $K = 5$ treatments, $v = 10$ degrees of freedom and using 0.01 as the significance level to give the result in Table 3.

Compressive strength at 14 days

At the end of 14 days curing, CRS blocks still had the highest strength at 2.23 MPa closely followed by CQD at 2.13 MPa, other blocks had lower strength values when compared with these two samples stated earlier (Fig. 4). Similarly F-statistics

Table 3
Tukey HSD statistical analysis of compressive strength at 7 days.

Treatment pair	Tukey HSD $Q_{statistic}$	Tukey HSD *P*-value	Tukey HSD inferfence
CRS vs CQD	1.3083	0.8738	Insignificant
CRS vs CRE	8.2346	0.0012	Significant
CRS vs CLT	8.0806	0.0014	Significant
CRS vs RLR	10.1842	0.0010	Significant

Table 4
Tukey HSD statistical analysis of compressive strength at 14 days.

Treatment pair	Tukey HSD $Q_{statistic}$	Tukey HSD *P*-value	Tukey HSD inferfence
CRS vs CQD	1.2245	0.8999	Insignificant
CRS vs CRE	9.6797	0.0010	Significant
CRS vs CLT	3.4404	0.1835	Insignificant
CRS vs RLR	11.1958	0.0010	Significant

Table 5
Tukey HSD statistical analysis of compressive strength at 21 days.

Treatment pair	Tukey HSD $Q_{statistic}$	Tukey HSD *P*-value	Tukey HSD inferfence
CRS vs CQD	0.1694	0.8999	Insignificant
CRS vs CRE	7.7237	0.0019	Significant
CRS vs CLT	0.20333	0.8999	Insignificant
CRS vs RLR	11.3826	0.0010	Significant

of One Way ANOVA gave a p-value lower than 0.01 which means that one or more of the blocks are significantly different. An increase in strength of CLT was noted from 7 to 14 days largely due to the cohesiveness of the lateritic soil, which bound the particles together as well as the increased bonding within the aggregates of the blocks which could as well increase the density therefore leading to a higher compressive value [1]. In order the ascertain the blocks that differ by comparing the strength of the respective blocks, Tukey HSD test with $Q_{statistic}$ was used based on $K = 5$ treatments, $v = 10$ degrees of freedom and using 0.01 as the significance level to give the result in Table 4.

Table 4 showed that there is significant effect of combination of all three alternative materials used (RLR) and quarry dust for the brick production when compared with the traditional material used for sandcrete blocks for the 14th day compressive strength. But, there is no significant differences when quarry dust and laterite were used possibly because of their strength were closely matched to the river sand material.

Compressive strength at 21 days

CRS, CQD and CLT sample blocks had values in the range of 2.25–2.37 MPa which is quite high when compared with values of CRE and RLR at 1.51 MPa and 1.15 MPa respectively (Fig. 4). One Way ANOVA of this result gave a *p*-value lower than 0.01 which indicates that one or more of the blocks are significantly different from each other. A further analysis with Tukey HSD at the same parameters stated earlier gave the results in Table 5.

CRE and RLR constituent materials showed a lower strength over the CRS at the end of the 21 days test; meanwhile CQD and CLT had little difference in terms of their strength performance when compared with the traditional material used for the sandcrete block development.

Compressive strength at 28 days

CRS, CQD and CLT sample blocks had 2.56, 2.53 and 2.46 MPa, respectively, while the values of CRE and RLR are 1.94 MPa and 1.58 MPa, respectively (Fig. 4). This showed that CQD has very close strength property to CRS and it is followed by CLT in order of their strength performance. The improved strength of CQD and CLT from 21 days to 28 days may be attributed to the better cement hydration over time [11,13]. One Way ANOVA of this result gave a p-value lower than 0.01 which indicates that one or more of the blocks are significantly different from each other.

River sand is brought down by river water from upstream it may possibly be of a widely different mineralogy and as a result its use in the block may have led to delayed hydration of cement due to the deleterious alkali aggregate reaction from the 7th to 21st day of curing. However its positive advantage lies in the fact that it is a rounded and smooth material which improved the packing density and increased the workability of the mortar produced, this improvement was observed on the 28th day with an increase in strength [15]. A smooth surface would improve workability, yet a rougher surface generates a stronger bond between the paste and the aggregate creating a higher strength. The size distribution of the aggregate is an important characteristic because it determines the paste requirement for workable concrete. This paste requirement is the factor controlling the cost, since cement is the most expensive component of it. It is therefore desirable to minimise the amount of paste consistent with the production of sandcrete blocks that can be handled, compacted, and finished while providing the necessary strength and durability. Hence most sandcrete block manufacturers prefer to use river sand to any

Table 6
Tukey HSD statistical analysis of compressive strength at 28 days.

Treatment pair	Tukey HSD $Q_{statistic}$	Tukey HSD *P*-value	Tukey HSD inferfence
CRS vs CQD	0.2081	0.8999	Insignificant
CRS vs CRE	4.3237	0.0719	Insignificant
CRS vs CLT	2.2428	0.5343	Insignificant
CRS vs RLR	6.7976	0.0050	Significant

other substitute. Using the same parameters, Tukey HSD analysis is shown in Table 6. CQD, CRE and CLT all showed that there is no significant difference in their strength property in comparison to CRS whereas RLR had a far lower strength property at the end of the test.

From these results, it could be confirmed that among the materials used for this experiment, quarry dust had the closest performance to the conventional river sand used in sandcrete block development and therefore it could be used as a prospective alternative to replace the more expensive and scarce river sand. This is largely due to the fact that quarry dust has rough, sharp and angular particles, and as such causes a gain in strength due to better interlocking [23]. In addition to this, this quarry dust usage will serve as a way of eliminating its disposal challenges in quarry companies thereby reducing environmental problem that it could pose to the environment. Lateritic soil's good performance under the compressive force is because they are granular in structure in their natural state and have low plasticity so they can carry heavy load [29]. Although the compressive strengths of some of the blocks were higher than 1.75 MPa (Fig. 4) as reported by the National Building Code 35, which states that the strength requirement of sandcrete hollow blocks must have the lowest strength of individual block as 1.75 N/mm^2 (250 psi). However, the compressive strength of the blocks is lower than the average compressive strength of sandcrete blocks produced manually by Odeyemi et al. [22] age 7, 14, 21 and 28 days of production with the strength ranging between 2.61 N/mm^2 to 2.89 N/mm^2. Similarly, the compressive strength values of manually mixed sandcrete blocks studied by Nwaigbe et al. [21] ranges from 0.81 N/mm^2 to 1.25 N/mm^2 which is lower than the obtained values in this research.

Conclusion

The mixture of quarry dust and lateritic soil gave the best performance when compared with the mixture of red earth and RLR when used as an alternative to river sand in the production of sandcrete blocks. The compressive strength of these two materials gave a close margin result to those of the river sand. The curing days adopted for the samples to harden also led to a further improvement in the observed strength. Quarry dust and lateritic soil could be used to replace river sand in sandcrete blocks. The research is also to simulate experimentally what is being done in most block making industries in the region. It was observed that mixing manually led to non-homogenous mixing of cement into the matrix which affected the strength of the blocks and this caused a higher increment in strength at 28 days than observed strengths from 14 to 21 days. It is suggested that mechanical mixing be adopted to further improve the strength of the blocks.

Declaration of Competing Interest

There is no conflict of interest.

Funding

There is no funding for this study.

References

[1] J.I. Aguwa, Performance of laterite-cement blocks as walling units in relation to sandcrete blocks, Leonardo Electron. J. Pract. Technol. 9 (16) (2010) 189–200.
[2] P.O. Awoyera, A.R. Dawson, N.H. Thom, J.O. Akinmusuru, Suitability of mortars produced using laterite and ceramic wastes: mechanical and microscale analysis, Constr. Build. Mater. 148 (2017) 195–203.
[3] H. Bal, Y. Jannot, S. Gaye, F. Demeurie, Measurement and modelisation of the thermal conductivity of a wet composite porous medium: laterite based bricks with millet waste additive, Constr. Build. Mater. 41 (2013) 586–593.
[4] H. Bal, Y. Jannot, N. Quenette, A. Chenu, S. Gaye, Water content dependence of the porosity, density and thermal capacity of laterite based bricks with millet waste additive, Constr. Build. Mater. 31 (2012) 144–150.
[5] J. Bredenoord, Sustainable housing and building materials for low-income households, J. Archit. Eng. Technol. 5 (1) (2016) 1–9.
[6] S.J. Chithambaram, S. Kumar, Flexural behaviour of bamboo based ferrocement slab panels with flyash, Constr. Build. Mater. 134 (2017) 641–648.
[7] H. Danso, D.B. Martinson, M. Ali, J.B. Williams, Physical, mechanical and durability properties of soil building blocks reinforced with natural fibres, Constr. Build. Mater. 101 (2015) 797–809.
[8] S. Erguden, Low-Cost housing: policies and constraints in developing countries, in: Proceedings of International Conference on Spatial Information for Sustainable Development Nairobi, Kenya, 2001, pp. 1–10.
[9] Federal Republic of Nigeria, National Building Code 35, 1st Edition, Federal Ministry of Power, Works and Housing, Nigeria, 2006 Section 10.3.144.
[10] M. Galetakis, C. Piperidi, A. Vasiliou, G. Alevizos, E. Steiakakis, K. Komnitsas, A. Soultana, Experimental investigation of the utilization of quarry dust for the production of microcement-based building elements by self-flowing molding casting, Constr. Build. Mater. 107 (2016) 247–254.

[11] V. Greepala, R. Parichartpreecha, Effects of using flyash, rice husk ash and bagasse ash as replacement materials on the compressive strength and water absorption of lateritic soil-cement interlocking blocks, in: Proceedings of the 9th Australasian Masonry Conference, 2011, pp. 583–603.
[12] R. Ilangovan, K. Nagamani, (2007). Application of Quarry Dust in Concrete Construction. High performance Concrete, Federal highway Administration PP1-3, 4(25), 2008 http://knowledge.fhwa.dot.gov/cops/hpcx.nsf.
[13] J. James, P.K. Pandian, K. Deepika, J. Manikanda Venkatesh, V. Manikandan, P. Manikumaran, Cement stabilized soil blocks admixed with sugarcane bagasse ash, J. Eng. 2016 (2016) 1–9.
[14] O. Joshua, K.O. Olusola, L.M. Amusan, I.O. Omuh, Recycling fine sandcrete block waste (FSBW) as fine aggregate in the production of sandcrete block, IJRRAS 15 (2013) 359–364.
[15] A.K.H. Kwan, Research on River Sand Substitutes for Concrete Production and Cement Sand Mortar Production (Phase One), Department of Civil Engineering, The University of Hong Kong, 2013 Accessed online on 01/09/2017 from https://www.cic.hk/cic_data/pdf/about_cic/news_and_update/past_event/eng/TF%2018-1-2013%20Presentation%20-%20Prof_%20Albert%20KWAN.pdf .
[16] P.N. Lemougna, U.F.C. Melo, E. Kamseu, A.B. Tchamba, Laterite based stabilized products for sustainable building applications in tropical countries: review and prospects for the case of Cameroon, Sustainability 3 (1) (2011) 293–305.
[17] H. Li, F. Huang, G. Cheng, Y. Xie, Y. Tan, L. Li, Z. Yi, Effect of granite dust on mechanical and some durability properties of manufactured sand concrete, Constr. Build. Mater. 109 (2016) 41–46.
[18] J.O.E.L. Manasseh, Use of crushed granite fine as replacement to river sand in concrete production, Leonardo Electron. J. Pract. Technol. 17 (2010) 85–96.
[19] A.K.B. Marsono, A.T. Balasbaneh, Combinations of building construction material for residential building for the global warming mitigation for Malaysia, Constr. Build. Mater. 85 (2015) 100–108.
[20] L. Mbumbia, A.M. de Wilmars, Behaviour of low-temperature fired laterite bricks under uniaxial compressive loading, Constr. Build. Mater. 16 (2) (2002) 101–112.
[21] D.N. Nwaigwe, E.A. Ogwu, M.C. Ugonna, O.D. Atakpu, A. Edom, Evaluation of the quality of hand moulded sandcrete block in Owerri, Imo State, Nigeria, J. Sustain. Dev. Stud. 8 (2) (2015) 252–259 ISSN 2201-4268.
[22] S.O. Odeyemi, O.O. Otunola, A.O. Adeyemi, W.O. Oyeniyan, M.Y. Olawuyi, Compressive strength of manual and machine compacted sandcrete hollow blocks produced from brands of Nigerian cement, Am. J. Civil Eng. 3 (2–3) (2015) 6–9.
[23] S.O. Osuji, B.N. Egbon, Optimizing compressive strength characteristics of hollow building blocks from granite quarry dust and sand, Niger. J. Technol. 34 (3) (2015) 478–483.
[24] C.A. Oyelami, J.L. Van Rooy, A review of the use of lateritic soils in the construction/development of sustainable housing in Africa: a geological perspective, J. Afr. Earth Sci. 119 (2016) 226–237.
[25] V. Puri, P. Chakrabortty, S. Anand, S. Majumdar, Bamboo reinforced prefabricated wall panels for low cost housing, J. Build. Eng. 9 (2017) 52–59.
[26] K. Shyam Prakash, C.H. Rao, Study on compressive strength of quarry dust as fine aggregate in concrete, Adv. Civil Eng. 2016 (2016).
[27] G.R. Subbarao, J.P.C. Rao, Cement stabilized red earth as building block and structural pavement layer, Constructii 15 (2) (2014) 49.
[28] J. Thomas, B. Harilal, Mechanical properties of cold bonded quarry dust aggregate concrete subjected to elevated temperature, Constr. Build. Mater. 125 (2016) 724–730.
[29] H.F. Winterkorn, E.C. Chandrasekharan, Lateritic Soils and Their Stabilization, Winterkorn Road Research Institute, 1951.