The Partial replacement of Ordinary Portland Cement with Rice Husk Ash to Stabilize Compressed Earth Blocks for Affordable Building Materials

ADEDAMOLA MOBOLANLE OJERINDE1, ADEKUNLE M AJAO2, BABATUNDE F OGUNBAYO2, VICKI STEVENSON1, ESHRAR LATIF1
1Cardiff university, United Kingdom
2Covenant university, Nigeria

ABSTRACT: The study investigated potentials of rice husk ash as a replacement for Ordinary Portland Cement in the production of Compressed Earth Block (CEB) with a view to reducing building construction cost and the embodied energy of the blocks in the context of Nigeria. Graded levels (i.e. 10, 20, 30 and 40%) of RHA replaced cement in the mix for CEB moulding. The results of X-ray diffraction showed that RHA contained 80% SiO_2. Also, the results of the compressive strength, water absorption capacity, and bulk density testing indicated that low compressive strength, high water absorption capacity, and low bulk density exhibited by RHA-CEB make doubtful the suitability of RHA as a partial replacement for Ordinary Portland cement in the building construction in the wet regions. However, RHA could find useful application as a stabilizing agent in CEB rather than as a partial replacement of cement.
KEYWORDS: Ordinary Portland cement, Rice Husk Ash, Compressed Earth Block, Low-Cost Housing.

1. INTRODUCTION

The rate of urbanization in Nigeria has increased significantly in the last decade. These episode has led to rise in population in the cities which has caused shortage of dwelling units. These shortage has led to overcrowding, high rent, poor living condition and poor infrastructure **[1]**. The need to provide low cost houses in Nigeria cannot be over emphasized. Indeed, Nigeria is estimated to have 17-million-unit housing shortfall, and unfortunately about 62% of Nigerians live below the international poverty line **[1],** which makes it difficult for them to afford modern day building. Over 90% of low-income earners cannot afford decent accommodation even if they saved 100% of their income for 10 years **[2]**. Government's efforts at solving the problem of housing shortage proved futile because it ended in providing costly and unaffordable houses.

It is noticed that construction materials accounts for 60-70% of the total cost of building construction **[3],** hence the use of cheaper, available and suitable alternative materials could contribute to housing sustainability in future. In this regard, use of earth material in building construction may find useful application. While the use of earth material is not new in Nigeria, it is necessary to improve the strength and durability of such construction materials if intended for the construction of multi dwelling unit.

Compressed earth block (CEB) is earth material that needs stabilization to improve on its mechanical properties **[4, 5].** The use of several agricultural waste products has been used as stabilizer in other building materials other than CEB, example of such agricultural waste includes rice husk ash **[5, 6],** waste sugarcane bagasse **[6, 7],** palm oil fuel ash **[8]**, sawdust or wood ash **[6]**, etc. RHA is preferred because the government has invested heavily in rice production to shift the economy from being crude oil-dependent to agriculture. By this the agricultural sector would increase and waste will be generated. Such agricultural wastes should therefore be reused to avoid the pollution which will be at the result of disposal.

Cost of cement has been of concern in the provision of sustainable housing. The production of cement leads to 7-8% global CO_2 emmision**[9]**. The material functions as a binding agent in compressed earth block moulding. Sourcing acceptable alternative low-cost binding agent will significantly reduce cost of providing housing. Rice husk ash, like other sustainable pozzolans will serve useful application here **[5, 6].** Kazmi **[10]** suggested that addition of RHA in brick manufacturing could lead towards sustainable and economical construction.

Apart from reducing cost, RHA's utilization in construction will displace the use of cement in the construction industry thereby reducing pollution as result of production and utilization of OPC. In 2010, construction industry utilized 32% global energy consumption. 19% of the total consumption was as a result of total energy was as a result of greenhouse gases **[11].** Rice husk ash can be used to produce alternative binder(pozzolan), a geopolymer or an alkali –activated binders, these binders can be used to produce 73% lower greenhouse gas emission, 43% less energy consumption, 25% less water when used in the production of conventional concrete **[9]**. Also, RHA requires lower embodied energy compared to cement hence its use will save energy cost **[12]**. Rice husk ash being a product of agricultural production will raise the farmers' income. It will be worthwhile to see the possibility of replacing cement with rice husk ash in compressed earth block.

The present study is aimed at investigating the potentials of RHA as a partial replacement for Ordinary Portland Cement in the production of CEB for the construction of residential houses.

2.0 MATERIALS

The materials to use for CEBs are; laterite soil, Ordinary Portland Cement (OPC) and RHA.

2.1 Lateritic soil

It has been described as highly weathered tropic or sub-tropical residual soil varying in size from clay size to gravel **[13]**. Features characterizing of strong weathering of silicates, the release of Iron oxides and prevalence of kaolin. They are formed from different geologies of silicate rocks and limestone **[14].** Laterite remains one of the best natural material to be used in CEB because its well graded soil that combines both cohesive (silt and clay) and non-cohesive soil (sand and gravel) part of soil which have natural binding property as well as present of most chemical binders. The colour varies from light brown to rusted red, when drainage is poor in laterite soil, black cotton soil is formed. **[13]**.

2.2 Ordinary Portland cement

Cement is manufactured from calcium carbonate in the form of crushed limestone or chalk and argillaceous material such as clay, marl or shale. The process involves decarbonisation of calcium carbonate (chalk or limestone) by expulsion of carbon dioxide and sintering **[15]**. During the production of OPC, the kiln is fired at temperature as high as 1480°C **[16]**.

The production of cement emits pollutants including carbon dioxide, sulphur dioxide and at extremely high temperature the material can emit heavy metals. Dust is another pollutant in the environment that can cause skin allergies**[17].**

2.3 Rice Husk Ash

The Chemical composition of RHA is largely dependent on the type of paddy, soil type and condition, geographical conditions, combustion temperature, and cooling method. RHA pozzolan is prepared by burning RH at a controlled temperature ranging from 600-800°C and cooled uniformly to maintain amorphous silica content of 77-95% **[8, 18-20]**. The X-ray Diffraction (XRD) device can be used to identify the different phases within RHA:

a. Cristobalite (Crystalline phase)
b. Glass phase – SiO_2 (amorphous phase)

The required phase for RHA in pozzolans is the amorphous state.

3.0 Production of Rice Husk Ash

Method 1

The rice husk ash used for the test was gotten form Abeokuta, Ogun state in Nigeria. The rice husk was first charred to remove the moisture and organisms from the waste using a local burning method in a local mud pot. The colour of the husk changed from cream to black and the husk reduced to about half its size in mass. The charred husk was then combusted in a furnace for about 2-3 hrs at temperature ranging from 550-780°C. The furnace was left to cool for about 24 hrs before the RHA was brought out of the furnace. The colour of the resulting rice husk ash was whitish grey colour.

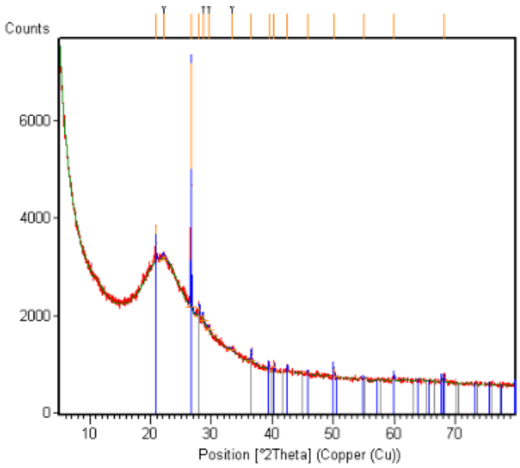

Figure 1. 80% SiO_2 (xrd analysis software)

Method 2

The rice husk was combusted directly in the furnace for $2^1/_2$ hrs- 3hrs. The colour of the rice husk changed from cream to whitish grey. The furnace was fed with the same quantity of husk used in 'method 1', the burning of the hush took a long time and cost more because the mass of the husk has not been reduced from the charring step which removes moisture and organisms. The second method was introduced to reduce the time of production process. A representative sample was analysed using XRD to establish that the RHA had a suitable proportion of amorphous material, which was confirmed (see Figure 2).

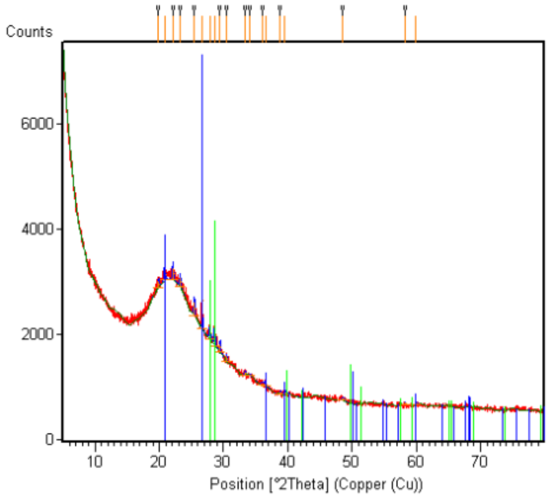

Fig 2 Method 2- 96% SiO_2 xrd analysis software

Pozzolan has been defined as siliceous or siliceous and aluminous material, which when in a finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties **[10].** The RHA used in this study contained amorphous SiO_2 of 80% (Figure 1) and 96% (Figure 2) that suggest it could have pozzolanic properties in the presence of moisture and cement. Also, that it could be used as stabilizing agent in CEB or as partial replacement for Ordinary Portland cement.

4.0 Experimental Procedure

The mix ratio 1:10 of OPC and laterite was used for the moulding of the control CEB. Then, the cement portion was replaced with graded levels of RHA at 10, 20, 30 and 40% to give five experimental treatments.

The resulting mixes were fed into the CEB Pressing machine to produced CEB with and without RHA inclusion. All the CEB were then allowed to cure for 14, 21 and 28 days. The blocks were placed on a platform outside in the open, covered with nylon, and then wet with water daily to achieve curing for the respective periods. The wetting prevented the blocks from drying fast and cracking during curing.

4.1 Laboratory Tests

Duplicate samples of blocks were removed randomly from the control and RHA-CEB treatment groups for laboratory tests. Compressive strength and water absorption capacity are tested as described in BS EN 771-1. Bulk density is described as the mass per unit volume each block.

4.2 Results

Results of compressive strength of experimental CEB cured for 14, 21, and 28 days are shown in Figure 3. The results show that compressive strength of the blocks varied with varying levels of RHA inclusion in the mix. The highest values were recorded in the control group (0% RHA) thus suggesting that inclusion of RHA in the mix resulted in the lowering of compressive strength.

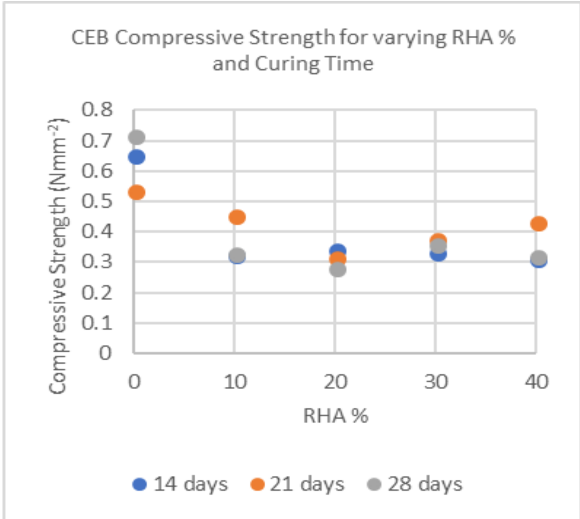

Figure 3. Compressive Strength of CEBs with varying RHA levels cured for 14, 21 and 28 days: (3 samples per data point given

The trend in the compressive strength of the CEB as affected by the RHA inclusion is depicted in Figure 3. Indeed, the results seemed to suggest that inclusion of RHA in the mix caused the reduction of strength by almost half.

The mean water absorption capacity of the test block samples is presented in Figure 4. The results show that RHA inclusion typically raised the water absorption compared to the control; however, the variation is not consistent. Among the samples with RHA inclusion, the least water absorption capacity value occurs for 20% RHA after 28 days curing.

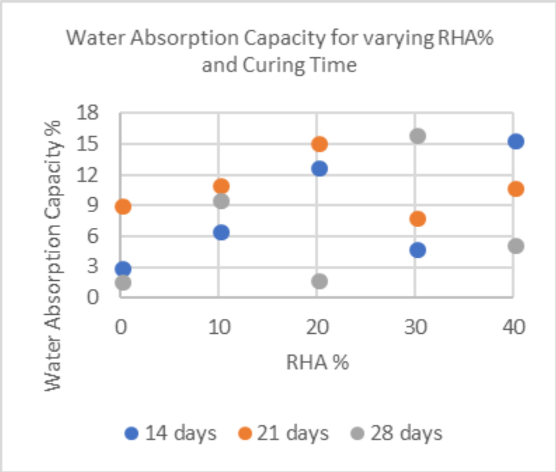

Figure 4. Water Absorption Capacity of CEBs with varying RHA levels cured for 14, 21 and 28 days: (3 samples per data point given

The results of the bulk density of the experimental CEB as affected by RHA inclusion is shown in Figure 5. That is, the bulk density values decreased with increasing duration of curing.

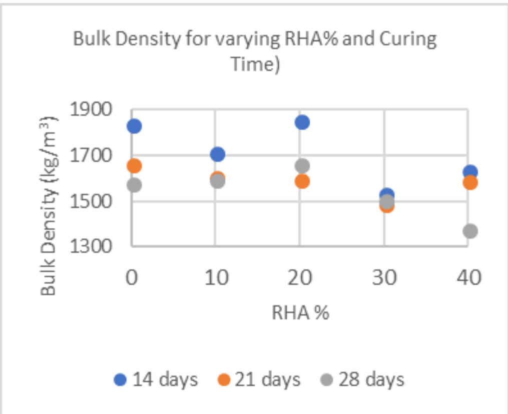

Figure 5. Bulk Density of CEBs with varying RHA levels cured for 14, 21 and 28 days: (3 samples per data point given)

5.0 DISCUSSION

Compressive strength, along with other parameters is an important parameter used in ascertaining the quality of materials for building construction. Consequently, compressive strength value as high as 3-4Nmm^{-2} and as low as 0.35Nmm^{-2} depending on the bulk density of stabilized CEB had been reported **[21, 22]**. In the present study, compressive stength for CEB with and without RHA inclusion ranged from 0.317-0.637Nmm^{2} (Fig. 3).

Futhermore, the authors noted that the variation in the compressive strength values reported for the CEB were due to the differences in the bulk densities (1800-2100kg/m^{3}) of the blocks **[22]**. Bulk density obtained in the present study (1513-1708 kg/m^{3}) for the CEB with and without RHA inclusion (Fig. 3) is lower than the range reported by Mansour **[22]**. The difference might be attributed to the differences in mixes used for the various CEB.

Bulk density, a function of the weight of material in a unit volume of space, depends on the extent to which the material is compressed per unit of space during block moulding. Conversely, water absorption capacity is a function of voids in the block. Therefore, an inverse relationship is expected to exist between bulk density and water absorption capacity. The results seemed to suggest that more earth material (laterite) should be used incorporated in the mix for CEB. Additionally, greater force should be applied in the block-pressing machine to increase the bulk density and compressive strength of the CEB.

In the present study, gradual replacements of cement with 0% to 40%RHA in the mix for CEB were tested. The results appeared to suggest that compressive strength and water absorption capacity tends to be stable at between 20 and 40%RHA inclusion, and that beyond 20% RHA inclusion, there was a remarkable decrease in the bulk density of the test block (Figures 5). Furthermore, RHA-CEB required 21 days of curing to raise its compressive strength, whereas it needed 28 days for keeping water absorption capacity at the barest minimum. Bulk density of RHA-CEB decreased with increasing duration of curing. A minimum of 21 days of curing appeared sufficient to stabilize the bulk density of the blocks (apart from with 40% RHA).

The suitability of RHA-CEB in the provision of low-cost housing for low-income earners needs to be addressed. It's generally low compressive strength, high water absorption capacity, and low bulk density make its suitability doubtful particularly in Nigeria where rainfall is heavy and persists for longer period of the year. However, its use in building construction might necessitate provision for protection from water in the architectural design of the building. That is, making provision for roof overhangs, elevated level of the foundation from the ground level, and using a damp proof course.

Furthermore, the results tended to suggest that RHA could not entirely replace cement in the CEB mix. As a pozzolan, RHA cannot show cementitious properties without the presence of calcium hydroxide $(CaOH)_2$ and water **[10].** Indeed, it needs cement to produce $Ca(OH)_2$ for the reaction with its silica to form calcium-silicate hydrate gel, the cementitious compound. Therefore, the use and application of RHA could probably be limited to a stabilizing agent rather than a replacement for cement.

6.0 CONCLUSION

The provision of a standard wall material for residential building need to meet some standard requirement in terms of mechanical, durability properties. The testing of compressive strength, bulk density and water absorption test was the first step taken to ensure adequate requirement was achieved.

From the foregoing, it may be concluded that low compressive strength, high water absorption capacity, and low bulk density exhibited by RHA-CEB make doubtful the suitability of RHA as a replacement for Ordinary Portland cement in the building construction in the wet regions.

However, the use of RHA in the CEB could be confined to serving as a stabilizing agent.

The result of the blocks (CEBS) did not meet the required standard which would need to be improved in further test carried out in the future.

- This can be achieved by exploring the inclusion of sharp sand to the mix proportion, increasing the bulk density of each unit of CEBs.
- Explore design modifications which could compensate for weakness of RHA stabilised blocks
- Explore passive design options appropriate to climate for small residential buildings to maximise comfort while respecting societal requirements.

7.0 REFERENCES

1. Ugochukwu, I.B. and M.I.B. Chioma, *Local Building Materials: Affordable Strategy for Housing the Urban Poor in Nigeria.* Procedia Engineering, 2015. 118: p. 42-49.
2. Awofeso, P. (2010). One Out of Two Nigerians now Lives in a City: There are Many Problems but One Solution. *World Policy Journal* 27:67
3. Khyomesh V.P and Chetna M.V., National Conference on Recent Trends in Engineering and Technology. Construction materials management on project sites, 2011.
4. Cid-Falceto, J., F.R. Mazarrón, and I. Cañas, *Assessment of compressed earth blocks made in Spain: International durability tests.* Construction and Building Materials, 2012. 37: p. 738-745.
5. Heung Fai, L.A.M., et al., *The Proceedings of the Twelfth East Asia-Pacific Conference on Structural Engineering and ConstructionStudy on Strength Characteristics of High Strength Rice Husk Ash Concrete.* Procedia Engineering, 2011. 14: p. 2666-2672.
6. Prusty, J.K., S.K. Patro, and S.S. Basarkar, *Concrete using agro-waste as fine aggregate for sustainable built environment – A review.* International Journal of Sustainable Built Environment, 2016. 5(2): p. 312-333
7. Domone, P.L.J. and J.M. Illston, *Construction materials : their nature and behaviour*. 4th ed. / edited by Peter Domone and John Illston. ed. Construction materials : their nature and behaviour, ed. P.L.J. Domone, J.M. Illston, and B. Dawson. 2010: London : Spon.
8. Alsubari, B., P. Shafigh, and M.Z. Jumaat, *Utilization of high-volume treated palm oil fuel ash to produce sustainable self-compacting concrete.* Journal of Cleaner Production, 2016. 137: p. 982-996.
9. Tong, K.T., R. Vinai, and M.N. Soutsos, *Use of Vietnamese rice husk ash for the production of sodium silicate as the activator for alkali-activated binders.* Journal of Cleaner Production, 2018. 201: p. 272-286.
10. Kazmi, S.M.S., et al., *Manufacturing of sustainable clay bricks: Utilization of waste sugarcane bagasse and rice husk ashes.* Construction and Building Materials, 2016. 120: p. 29-41.
11. Darko, A., et al., *Driving forces for green building technologies adoption in the construction industry: Ghanaian perspective.* Building and Environment, 2017. 125(Supplement C): p. 206-215.
12. Prasara-A, J. and S.H. Gheewala, *Sustainable utilization of rice husk ash from power plants: A review.* Journal of Cleaner Production, 2017. 167: p. 1020-1028.
13. Oyelami, C.A. and J.L. Van Rooy, *A review of the use of lateritic soils in the construction/development of sustainable housing in Africa: A geological perspective.* Journal of African Earth Sciences, 2016. 119: p. 226-237
14. Preetz, H., et al., *Relationship between magnetic properties and reddening of tropical soils as indicators of weathering.* Geoderma, 2017. 303(Supplement C): p. 143-149.
15. Lyons, A., *Materials for architects and builders*. Fifth edition. ed. 2014: London : Routledge.
16. Horsley, C., M.H. Emmert, and A. Sakulich, *Influence of alternative fuels on trace element content of ordinary portland cement.* Fuel, 2016. 184: p. 481-489.
17. Richardson, B.A., *Defects and deterioration in buildings*. 2nd ed. ed. 2001, London: London : Spon.
18. Chiang, K.-Y., et al., *Lightweight bricks manufactured from water treatment sludge*

and rice husks. Journal of Hazardous Materials, 2009. 171(1–3): p. 76-82.

19. Ganesan, K., K. Rajagopal, and K. Thangavel, *Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete.* Construction and Building Materials, 2008. 22(8): p. 1675-1683.
20. Sore, S.O., et al., *Synthesis and characterization of geopolymer binders based on local materials from Burkina Faso – Metakaolin and rice husk ash.* Construction and Building Materials, 2016. 124: p. 301-311.
21. Mostafa, M. and N. Uddin, *Experimental analysis of Compressed Earth Block (CEB) with banana fibers resisting flexural and compression forces.* Case Studies in Construction Materials, 2016. 5: p. 53-63.
22. Mansour, M. B. et al. 2016. Optimizing thermal and mechanical performance of compressed earth blocks (CEB). *Construction and Building Materials* 104, pp. 44-51. doi: http://dx.doi.org/10.1016/j.conbuildmat.2015.12.024

ACKNOWLEDGEMENTS

I would also like to appreciate Covenant University, Nigeria for provision of facility to carry out necessary test.