Eco-Friendly Use of Guinea Corn Straw as Building Material in Construction for Sustainable Development

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Abstract
Globally, million tonnes of straws are produced annually from farms as agricultural wastes. Walls made from plastered straw bale blocks are known to have low thermal conductivity and provide insulation for houses when used in building construction. In this study, the use of guinea corn straw encapsulated in cement mortar to produce masonry units for construction of building was carried out.The baled straws were manually compressed and tightly bound with twine purposely to avoid looseness, thus increasing the density of bale. Construction of wooden moulds of inner sizes of 150mm x 200mm x 400mm for straw brick blocks was adopted catering for mortar thickness of 50mm as cover for adequate protection of the baled straw encased. The average compressive strength of mortar used was determined, the density and strength of the resulting masonry units were also determined. A prototype building of plan dimension 5000 mm x 3000 mm was constructed with the use of straw brick blocks. The average compressive strength of the mortar was 11.11N/mm^2, the density and strength of the straw bale block was found to be 62.86 kg/m^3 and 1.87N/mm^2 respectively. These values meet the minimum specification outlined in BS5628-1:1992 for masonry unit standard for building construction. The cost of producing a square meter of wall with straw block was compared with that of the conventional sandcrete block. The comparison showed that the use of straw block in wall construction reduced the cost of producing blocks by almost 35%.
Keywords: straw bale, straw block, compressive strength

Introduction
According to United State Environmental Protection Agency (USEPA), green building is defined as the practice of creating structures and using processes that are environmentally responsible and resource efficient throughout a building's life-cycle from sitting to design, construction, operation, maintenance, renovation and deconstruction. It is also known as sustainable or high performance building. The overall impact of the built environment on human health is greatly reduced when eco-friendly materials are used as building materials (USEPA, 2015).Whole Building Design Guide sustainable committee (WBDG, 2014) reported that building construction and operation may have elaborate direct effect on the environment, society and economy, which is mostly the major way of evaluating the desirability of a project in absolute term. The globe's population today has reached 7 billion people and by 2030, it is expected to have reached 8-10 billions, taking into consideration the unprecedented growth rate and limited resources, there is a need to protect resources and habitat without marginalizing human rights (WBDG, 2014).

Many researchers have made considerable effort to optimize building design for energy efficiency. Some studies used the operating energy consumption or life-cycle cost as the performance criterion to establish optimization model (Ajamu and Adedeji 2013; Coley and Schukal, 2002). Green building structures are energy efficient, conserved resources, create healthier indoor environments and offer durable and beautiful spaces that use environmentally suitable materials (Peter *et. al.*, 2012). Green environment building incorporates integrated design concepts, solar orientation, appropriate foot point sizing glazing awareness, material durability, economic life cycle analysis, material reuse and salvage, natural material content, locally available materials and economic sustainability. Relative thermal insulation test result, reported by Ajamu and Adedeji (2013) shows that walls constructed with cement plastered straw bale are better in thermal insulation compared to sandcrete block wall

Historically, Buildings in the United States were constructed with locally available and generally sustainable materials. These materials were often indigenous to the region and resulted in unique design solution based on their availability and the climate where the building was constructed. Typical American home is a collection of materials from every corner of the continent and from suppliers across the globe. Green builders acknowledge the environmental impacts of materials selected and stripped long distances and make appropriate design choices (Craig *et. al.,* 2009). It is also known as a sustainable or high performance building.

The use of encapsulated guinea corn straw in cement mortar to form solid block units for building construction in Nigeria was explored in this study.

Materials and Methods
Materials acquisition
Straw obtained from guinea corn stalks was used in this project. It was left in the open space to dry for one week

after acquisition from a local farm (Figure 1). The useful straws were cleaned, free from debris and other leaves. The material is usually obtained between December and February when farmers are preparing to clear their farms for the raining season farming. Ordinary Portland cement was used to prepare mortal with potable water. Fine aggregate used were also cleaned, soft, well graded natural sand free from salt and organic contaminants. The straws were cut to size of 300mm long using cutlass and were held together with string. The baled straws were manually compressed and tightly bound with twine purposely to avoid looseness (Figure 2a, b, c)

Figure 1: Gathered stalks of guinea corn straw

Figure 2a: Cutting of the straw to 300mm length

Figure 2b: Binding of the straw to bales with string

Figure 2c:Guinea corn straw bales ready for use

Fabrication of wooden moulds

Construction of wooden mould of inner sizes of 150mm x 200mm x 400mm for straw brick blocks was adopted catering for mortar thickness of 50mm as cover for adequate protection of the baled straw encased. The ratio of the cement to sand used for mortar is 1:6 and compressive strength test was carried out on the mortar produced. With the mortar produced, a bed of 50mm thick was first laid inside the wooden mold thereafter the straw bale was placed over it; spaces at the sides and top were filled with the mortar as shown in Figure 3a. The bricks were de-molded and allowed to cure by wetting for 28 days and were also allowed to dry naturally before use.

Though smooth surface of the inner mould was achieved but lubrication oil was as well used for easy removal of the specimen. The blocks were de-molded immediately and curingof the block commenced the following day by wetting for 28days before they were used. Figure 3a shows the processes of molding the block while Figure 3b shows the freshly de-molded straw blocks.

Figure 3a: Production straw blocks

Figure 3b: Freshly de-molded straw blocks

Density and Compressive Strength Test of Straw Block Units

The result of the compressive strength test carried out on the mortar used is presented in Table 1 while those of the density and compressive strength tests carried out on the sample blocks with encased straw are as presented in Table 2.

Results and Discussion

Table 1: Compressive strength result for mortar

Age of cube (Days)	Load at failure (kN)			Average failure load (kN)	Compressive strength f_c (N/mm^2)
	Sample 1	Sample 2	Sample 3		
3	65.00	64.21	65.50	64.90	2.89
7	77.51	76.50	77.20	77.07	3.43
14	125.50	124.60	127.11	125.74	5.59
21	209.25	208.27	205.15	207.56	9.22
28	250.55	250.67	248.51	249.91	11.11

The 28 days result satisfies the minimum site test requirement for mortar designation (i) of Table 1 of BS5628.

Table 2: Compressive test results at 28 days for blocksencased straw

Specimen Number	Weight (kg)	Density (kg/m^3)	Load at failure (kN)	Load Bearing Area (mm^2)	Strength (N/mm^2)
1	7.50	62.50	148.00	80000	1.85
2	7.61	63.42	148.00	80000	1.85
3	7.52	62.67	152.00	80000	1.90
Average	7.54	62.86	149.33	80000	1.87

The 28 days result satisfies the minimum requirement for non - load bearing block for wall construction by NIS 87: 2000

Samuel (2014) and Joan *et., al.* (2014) from their different findings reported the average density of 1681 kg/m^3 and 1710 kg/m^{3}and compressive strength of (0.92 – 2.4) N/mm^2 and (1.55 – 1.76) N/mm^{2}for commercially available sandcrete block in Nigeria. The straw block had relatively low density but this did not significantly affect its compressive strength.

A prototype building of plan dimension 5000 mm x 3000 mm was constructed with the use of straw blocks. Post and beam (non-load bearing) method of construction was adopted as the wall was constructed between posts supporting the roof (Figure 4a). A section through the straw block shows the position of the straw embedded in the mortar (Figure 4b).


Figure 4a: Construction straw block walled building


Figure 4b: Section through the straw block

Comparison of the Cost Analyses of the Straw Block with the Conventional Sandcrete Block

As at the time of this study, the cost analysis was based on the cost of producing a square meter of wall with straw block and with conventional sandcrete block

Cost analysis of bales

For a building with plan dimension of 5m x 3m with a height of 3m, about 500units of straw bricks of 150 x 200 x 400 mm were used for the construction (excluding the materials used for foundation), the total cost of production of the straw blocks was N35,000 which covered the cost of cement, sand, water and labour cost for the production.

The unit cost of production of straw block = N35,000/500 = N70.00

If 150 mm (6 inches) sandcrete block were to be used, about 490 units will be required.

Unit cost of the sandcrete block = N110

The cost of 490 units of the block = N110 x 490 = N53,900

Cost saving with the use of straw block = N53,900 – N35, 000 = N18,900

The percentage saving in the cost of block production = (18900/ 53900) x 100 = 35.1%

Conclusion

Based on the results of this study, the following conclusions were drawn:

(i) The use of guinea corn straw encapsulated in cement mortar produced blocks with very low density (62.86 kg/m^3) without compromising the compressive strength (1.87 N/mm^2).

(ii) The use of straw block in wall construction reduced the cost of the building blocks production by 35.1% when compared with that of the conventional sandcrete block.

(iii) The use of guinea corn straw in the production of straw blocks provided an eco-friendly sink for the large volume straws generated as agricultural wastes.

Recommendations

The following recommendations are made from findings:

(i) The straw blocks should be used in post and beam (non-load bearing) method of construction.

(ii) Wherever engineer's specification suggests light weight structure to be constructed, the use of straw block for wall construction is recommended for use.

(iii) The good percentage of cost saving in wall construction using the straw will make the provision of affordable housing for larger population of people.

References

Ajamu S. O. and Adedeji A. A. (2013): "Investigating the Bearing Capacity of Straw Bale Masonry in Compression and Thermal Loads". Websjournal of Science and Engineering Application (WESAE), 2 (1), pp. 50-58.

Arimanwa, J. I., Arimanwa, M. C., Okere, C. E. and Awodiji, C. T. G. (2014): "Assessment of the Quality of Sandcrete Blocks In Use in Owerri Imo State, South-East Nigeria" International Journal of Engineering and Innovative Technology (IJEIT), 3 (1), pp. 196 – 206.

British Standards Institution (1992): "Code of practice for useof masonry - Part 1: Structural use of unreinforcedMasonryBS 5628-1:1992.

Coley, D. A. and Schukal, S. (2002). Low-Energy Design: Combining Computer-Based Optimization and Human Judgment, Building and Environment, 37, pp.1241-1247

Craig N. Connie B. W. and Dave C. (2009): "Green Building Guide: Design Techniques, Construction Practices & Materials for Affordable Housing" Published by Rural Community Assistance Corporation (RCAC) Office: 3120 Freeboard Drive, Suite 201, West Sacramento, California 95691916/447-2854 | 916/447-2878 fax | *www.rcac.org*

Nigerian Industrial Standard (2000): "Standard for Sandcrete Blocks." NIS 87:2000, SON, Lagos, Nigeria

Peter O. A., Ezekiel A. C. and Paul O. O. (2012). "Design of a Sustainable Building: A Conceptual Framework for ImplementingSustainability in the Building Sector" ISSN 2075-5309 www.mdpi.com/journal/buildings/

Samuel S. O. (2014). "An Assessment of the Compressive Strength of Solid Sandcrete Blocks in Idiroko Area of Nigeria". Research Journal in Engineering and Applied Sciences 3(1) 38-42 ISSN: 2276-8467 www.emergingresource.org

USEPA (2015): "What is a Green Building? Retrieved on 14/05/2015 http://www.conserve-energy-future.com/green-building.php

Whole Building Design Guide (2014).Sustainable, National Institute of Building Sciences, www.wbdg.org/design/sustainable.php

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