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Cost Evaluation of Utilising Building Materials Derived from Agricultural Waste as Sustainable Materials for Lightweight Construction

Usman Aliyu JALAM, Abdurrahman Aliyu JALAM, Ibrahim M. SALE
Abubakar Tafawa Balewa University Bauchi, Nigeria

Olorunmeye Fredrick JOB
University of Jos, Nigeria

Abstract: Efforts from laboratory experiments and some practical approaches show that several building materials can be derived from agricultural waste and be used as partial or complete replacement of conventional building materials. These efforts however have not completely provided the solution for the need of alternative building materials. This is due to the lack of generalised information on the development of the materials, which most often test few properties of the materials, and without any meaningful studies of the economic implication of the innovations. This research work was aimed to establish whether there is cost benefit in utilising building materials derived from agricultural waste or not, and to what extent if any? The cost of utilising Ordinary Portland Cement (OPC), Rice Husk Ash (RHA), and Oil Palm Shell (OPS) in concrete, sandcrete blocks, bonding and plaster mortars was then evaluated. The cost was arrived at by adopting the actual cost of the material by volume and multiplying it by the actual quantity by volume used. The study discovered that 41% cost reduction in mass concrete is the highest cost saving while 12% in plaster mortar is the lowest. An overall cost saving of about 24% in the total cost of materials recorded. However, the study discovered that overall cost saving is dependent on the distance of the agricultural waste from production or construction site. Lack of readily available appropriate technology for processing some of the agricultural waste to building material was identified as a major challenge.

Keywords: Cost, Agricultural Waste, Sustainable Materials, Lightweight Construction

JEL codes: at, least, two, JEL, codes

Correspondence Address: Usman Aliyu Jalam, /Department of Architecture, Faculty of Environmental Technology, Abubakar Tafawa Balewa University / P.M.B. 0248 Bauchi, Nigeria. Tel.: +2348023502394. E-mail: arcusmanjalam@gmail.com

1. Introduction

Modern building industry lays much emphasis on sophisticated construction techniques and building materials, which are cost and energy intensive. Traditional materials like clay, sand, stone, gravels, cement, brick, block, tiles, distemper, paint, timber and steel are being used as major building components in the construction sector. All these materials have been produced from the existing natural resources and will have intrinsic distinctiveness for damaging the environment due to their continuous exploitation. So also, during the process of manufacturing various building materials, especially decomposition of calcium carbonate, lime and cement manufacturing, high concentration of carbon monoxide, oxides of sulphur, oxides of nitrogen and suspended particulate matter are invariably emitted to the atmosphere. Atmospheric dust burden around the manufacturing industries is often much higher than the standard ambient air quality (Osha *et al*, 2005). Exposure to such toxic gases escaping into the environment does lead to major contamination of air, water, soil, flora, fauna, and aquatic life and finally influences human health and their living conditions (Pappu *et al*, 2007). Shelter, which has universally been accepted as one of the three basic human needs (food, shelter and clothing) (Folowosele, 2000; Apochi and Achuene 2002; and Achuenu and Achuenu 2010), is majorly a product of light-weight construction, particularly in developing countries. Achuenu and Achuenu (2010) stressed the fact that of the three basic needs of man, shelter has remained the most inadequately supplied all over the world. In developing countries, shelter as a problem, has manifested in both the rural and urban areas featuring in a number of different forms. Achuenu and Achuenu (2010) identified incessant increase in price of building materials including cement and aggregate as one of the major problems facing effective delivery of a large number of development projects.

On another hand, the continuous dumping of agricultural wastes and by-products such as rice husks (RH) and oil palm shell (OPS) in areas where rice and palm oil are cultivated and processed has resulted and constituted a great environmental nuisance. For instance, more than 100,000,000 metric tons of rice husk are generated each year throughout the world (Velupillai *et al*, 1996). Jalam *et al* (2014) reported that an average of between 691,.85 x 10^3MT and 816.19 x 10^3MT of rice husk from rice paddies is generated in Nigeria annually. Similarly, in 2014, United States Department of Agriculture reported that about 62.8 million metric tons of palm oil is produced globally every year. Of the total global production of palm oil, Nigeria contributes an average of about 930, 000 MT (World Index, 2014). At oil palm mills, when the fresh fruit bunches (FFB) are processed and oil extraction takes place, solid residues and liquid wastes are generated. These by-products include empty fruit bunches, fibre, shell, and effluent. Of these by-products, the shell is the most disturbing. Teo *et al* (2006) reported that except for the psifera species (which has virtually no shell to the kernel); the shell of oil palm comprises approximately 10% to 50% of the total composition of the oil palm fruitlets.

The disposal of the already accumulated agricultural wastes and their increasing annual generation has created a growing concern, which are mostly being burnt thereby contributing considerably to global warming. This growing concern for global pollution coupled with the increasing demand for low cost building materials particularly in the developing countries and the concern for resource depletion has challenged researchers to seek and develop new materials relying on renewable resources. These include the use of by-products and waste materials in building construction.

Exploiting agricultural waste material will not only maximise the use of the agricultural products, but will also help preserve natural resources and maintain ecological balance (Teo *et al*, 2006). Consequently, in view of the importance of saving energy, conservation of resources, pollution prevention and subsequently economic sustainability, efficient recycling of solid wastes is now a global concern requiring extensive research and development work towards exploring newer applications and maximising use of existing technologies for a sustainable and sound environmental management.

Today, ample results from laboratory experiments show that several building materials can be derived from agricultural waste and be used as partial or complete replacement of conventional building materials. Teo *et al* (2006) carried out a study to investigate the performance of oil palm shell (OPS) as lightweight aggregate in structural concrete and concluded that with a compressive strength of 28.1N/mm^2 at an age of 28 days, OPS can be used as a coarse aggregate in structural concrete production and can even be used for low to moderate strength application such as structural members for low-cost houses. Similarly, Oyejobi *et al* (2012) reported that 20.1N/mm^2 compressive strength at 28 days hydration period was obtained from a concrete mix of 1:1.5:3 using OPS as aggregates which also met the British Standard recommended minimum strength of 15N/mm^2 for structural lightweight concrete. These two studies confirmed earlier studies by Mannan and Ganapathy (2004) and Teo *et al* (2005). Earlier, Rahman (1987); Achuenu (2005);

Oyekan and Kamiyo (2007); Oyekan and Kamiyo (2011); and Chik et al (2011) confirmed that rice husk ash (RHA) could be used to reduce the Ordinary Portland Cement (OPC) in concrete and sandcrete block mortar. However, while Oyetola and Abdullahi (2009) and Allen (2010) reported that the optimum replacement level of OPC with RHA is 20%, Achuenu and Achuenu (2010) replaced the OPC with 30% RHA in concrete mix of 1:1:2 (OPC-RHA:Sand:Periwinkle Shell) and obtained a concrete of 8.74N/mm^2. Similarly, Oyetola and Abdullahi (2009) concluded that a sandcrete block of about 3.65N/mm^2 and density of about 1807.32kg/m3 could be obtained by replacing 20% of OPC with RHA.

However, the aforementioned efforts have not completely provided the solution for the need of alternative building materials. This is due to the lack of generalised information on the development of the materials, which most often test few properties of the materials, and without any meaningful studies of the economic implication of the innovation. A study by Achuenu and Achuenu (2010) evaluated the cost of a self-help/partnership initiative for low-cost housing integrating indigenous building materials in Nigeria. The study was however limited to the use of OPC, RHA and Periwinkle shells in concrete and laterite in producing compressed earth bricks for walling. This research work thus aimed at establishing whether there is cost benefit in utilising building materials derived from agricultural waste or not, and to what extent if any?

2. Methods and Materials

The research was designed based on a paired comparison between two groups of building materials. Conventional building materials formed one group as the control while building materials obtained from agricultural waste formed the other group as the treatment. The conventional building materials were obtained locally while the building materials derived from agricultural wastes were processed according to the procedures established in literature and as standards.

The OPS aggregate was obtained from Lafiya town of Nasarawa State in the north-central part of Nigeria at local oil palm mill. The transport cost of 1m^3 of the OPS per kilometre from the mill to the point of utilisation was recorded. The RHA used was from a locally sourced rice-husks (RH) burnt in a kiln under a controlled temperature of 700^{o}C and was later pulverised according to the Indian Standards for pozzolana (1344). The transport cost of 1m^3 of the husk per kilometre from source of the husk to the kiln was recorded. The quantity and cost of kiln fuel was also recorded. The quantity of RHA obtained from 1m^3 of RH was also recorded.

The characteristic performance of the materials derived from agricultural waste have earlier been well established to be adequate enough for incorporation as full or partial replacement of the conventional materials as reported in Rahman, (1987); Teo *et al* (2005); Achuenu (2005); Teo *et al* (2006); Oyekan and Kamiyo (2007); Oyetola and Abdullahi (2009); Allen (2010); Achuenu and Achuenu (2010); Oyekan and Kamiyo (2011); Chik *et al* (2011); and Oyejobi *et al* (2012).

Two gazebos were built. One of the gazebos was constructed using the conventional building materials, as a control (Appendix I) and the other was built with the materials obtained from the agricultural waste, as a treatment (Appendix II). Fine aggregate, water, timber, zinc roofing sheet and nails were used for both the control and the treatment. Cost evaluations of the treatment gazebo were compared with those of the control gazebo. The costs were arrived at by absolute quantity-cost analysis and valuing the cost in Naira. Since similar labour was implored in both the control and the treatment gazebos, cost of labour was not considered in the cost analysis.

3. Results and Discussions

3.1 Concretes

Tables 1 and 2 show a comparative cost analysis of the control and treatment mass concretes (1:3:5) and a comparative cost analysis of the control (1:2:4) and treatment (1:2:3.5) reinforced concretes respectively.

Table 1. Comparative Cost Analysis of the Control and Treatment Mass Concrete.

CONTROL			TREATMENT		
Material	Quantity (m^3)	Cost (Naira, N)	Material	Quantity (m^3)	Cost (Naira, N)
OPC	0.08	5, 069	OPC	0.07	4, 435
River sand	0.25	417	RHA	0.02	320
Crushed granite	0.49	3, 267	River sand	0.27	450
			POS	0.46	-
Total	**0.82**	**8, 752**	**Total**	**0.82**	**5, 205**

Source: Authors' own elaboration.

Table 2. Comparative Cost Analysis of the Control and Treatment Reinforced Concrete.

CONTROL			TREATMENT		
Material	Quantity (m^3)	Cost (Naira, N)	Material	Quantity (m^3)	Cost (Naira, N)
OPC	0.13	8, 237	OPC	0.11	6, 970
River sand	0.27	450	RHA	0.03	480
Crushed granite	0.53	3, 533	River sand	0.29	483
			POS	0.50	-
Total	**0.93**	**12, 220**	**Total**	**0.93**	**7, 933**

Source: Authors' own elaboration.

A total of 0.82m^3 of mass concrete was used and cost about N 8, 752 and N 5, 205 for the control and treatment concretes respectively. A total cost saving of N 3, 547 representing about 41%, was achieved in the treatment concrete. OPC, constituting about 10% in the control concrete, is the least constituent by volume but the most expensive contributing about 58% of the total cost.

For the reinforced concrete, a total of 0.93m^3 concrete was used each in the control and treatment reinforced concretes. While it cost N 12, 220 for the control concrete, it cost just N 7, 933 for the treatment concrete indicating a saving of about N 4, 287. This represents about 35% savings in terms of cost of materials.

In both the mass and reinforced concretes, the major areas of savings identified are in the binding agent (OPC and RHA) and the coarse aggregates (crushed granite and OPS). About 6% and 10% cost savings were achieved in the binding agent by replacing OPC with RHA at 20% replacement in the mass and reinforced concretes respectively. A corresponding 20% cost saving could not be achieved due to the fact that the sums of N 320 and N 480 were incurred in the process of burning RH to obtain the 0.02m^3 and 0.03m^3 of RHA used in the respective concretes.

100% cost saving in the treatment coarse aggregate was possible because there was no cost incurred in processing the OPS. Weathering was the only act of processing that was involved here and it was done naturally by allowing the OPS exposed to weather elements in an open space for a period of over one year.

3.2 Sandcrete Blocks

Table 3 shows a comparative cost analysis of the control and treatment sandcrete blocks used by volume of constituents. The sandcrete blocks used for the construction of the control gazebo cost about N 15, 376 while it costs about N 13, 395 for the specimen gazebo. This indicates a cost saving of about N 1, 981 representing about 13%. The only major area of cost saving identified is in the binding agent (OPC and RHA). A change in percentage cost saving would have been recorded if a mortar mix ratio of 1:8 was used.

Table 3. Comparative Cost Analysis of the Control and Treatment Sandcrete Blocks.

CONTROL			TREATMENT		
Material	Quantity (m^3)	Cost (Naira, N)	Material	Quantity (m^3)	Cost (Naira, N)
OPC	0.20	12, 760	OPC	0.16	10, 138
River sand	1.57	2, 616	RHA	0.04	640
			River sand	1.57	2, 617
Total	**1.77**	**15, 376**	**Total**	**1.77**	**13, 395**

Source: Authors' own elaboration.

3.3 Sandcrete Blocks Bonding Mortar

A total of 0.13m^3 of bonding mortar was used for each of the gazebos. The mortar costs N 2, 068 and N 1, 594 for the control and treatment gazebos respectively as can be seen in Table 4. This indicates a cost saving of N 474 representing about 23%, in the use of RHA as a replacement binding agent in sandcrete block bonding mortar.

Table 4. Comparative Cost Analysis of the Control and Treatment Sandcrete Blocks Bonding Mortar (1:3)

CONTROL			TREATMENT		
Material	Quantity (m^3)	Cost (Naira, N)	Material	Quantity (m^3)	Cost (Naira, N)
OPC	0.03	1, 900	OPC	0.02	1, 267
River sand	0.10	167	RHA	0.01	160
			River sand	0.10	167
Total	**0.13**	**2, 068**	**Total**	**0.13**	**1, 594**

Source: Authors' own elaboration.

3.4 Plaster Mortar

0.49m^3 of plaster mortar was used for each of the gazebos. The mortar costs N 8, 096 and N 7, 149 for the control and treatment gazebos respectively as can be seen in Table 5. This indicates a cost saving of N 947 representing about 12%, in the use of RHA as a replacement binding agent at

20% replacement level of OPC in plaster mortar. A corresponding 20% cost saving could not be achieved due to the fact that the sum of N320: 00 was incurred in the process of burning RH to obtain the 0.49m^3 of RHA used in the mortar.

Table 5. Comparative Cost Analysis of the Control and Treatment Plaster Mortar (1:3, 13mm thick).

CONTROL			TREATMENT		
Material	Quantity (m^3)	Cost (Naira, N)	Material	Quantity (m^3)	Cost (Naira, N)
OPC	0.12	7, 603	OPC	0.10	6, 336
River sand	0.37	493	RHA	0.02	320
			River sand	0.37	493
Total	**0.49**	**8, 096**	**Total**	**0.49**	**7, 149**

Source: Authors' own elaboration.

3.5 Overall Costing

Table 6 shows the overall summary of the cost of the materials incorporating agricultural waste in the various elements of the specimen gazebo in comparison with the control gazebo which does not incorporate any agricultural waste as a material.

Table 6. Summary of Comparative Cost Analysis of the Control and Treatment Gazebos.

CONTROL		TREATMENT	
Element	Cost (Naira, N)	Element	Cost (Naira, N)
Weak Concrete	8, 752	Weak Concrete	5, 205
Reinforced Concrete	12, 220	Reinforced Concrete	7, 933
Sandcrete Block	15, 376	Sandcrete Block	13, 395
Bonding Mortar	2, 068	Bonding Mortar	1, 594
Plaster Mortar	8, 096	Plaster Mortar	7, 149
Total	**46, 512**	**Total**	**35, 276**

Source: Authors' own elaboration.

It can be seen that an overall cost savings of about N 11, 236 representing 24% was achieved. This overall cost assumes that both the RH and the OPS were used at the point of their generation as waste and thus, no additional cost was incurred by means of transport.

3.6 Cost - Distance Relationship

The most significant cost associated with the utilisation of rice husk, to obtain rice husk ash, and oil palm shell as coarse aggregate, is their transportation from the point of their generation as waste to the point of utilisation. Additional challenge associated with the processing of RH to RHA is the cost of burning the husk into pozzolanic material due to lack of furnaces and kilns. From Table 7, it can be seen that in the production of its ash, 1m^3 of RH at a loose density of about 455kg/m^3 is transported from its point of generation to the point of burning at the cost of about N 220/km. That is to say N 1, 222 is required to obtain 1m^3 of RHA at a distance of 1km away from the point where RH is being generated as waste using a fuel-free furnace. On the other hand, the on-site cost of 1m^3 of OPC is N 63, 370. This represents the cost of transporting 5.6m^3 of RH over a distance of about 52km in order to obtain 1m^3 of RHA. This implies that it is only economical to use RHA obtained from RH transported within a radius of about 52km away from the point of generating it as a waste.

Table 7. Transport Cost and Processing of 1m^3 of RH and OPS

S/N	Item	Value
1.	Rice Husk	N 220/km
2.	Kiln Fuel per 1m^3 of Husk	57.6ltrs (N 2, 880)
3.	Ash Obtained from 1m^3 of Husk	0.18m^3
4	Oil Palm Shell	N 270/km
5.	Weathering of OPS	-
6.	OPS Obtained from 1m^3 of OPS	1m^3

Source: Authors' own elaboration.

Similarly, as shown in Table 7, it cost about N 270 to transport 1m^3 of OPS over a distance of 1km. On the other hand, the on-site cost of 1m^3 of 19mm machine crushed granite is N 6, 667. This represents the cost of transporting 1m^3 of OPS over a distance of about 25km away from source. As such, people living more than 25km away from palm oil mills would have a hard time justifying the economical use of OPS in place of crushed granite except if the cost of the crushed granite in that area exceeds N 6, 667/m^3.

4. Conclusions and Recommendations

From the results obtained and the discussions that followed, it can be concluded that savings could be achieved by utilising RHA obtained from RH, and OPS as partial and complete replacement of the conventional building materials - cement and coarse aggregate. An overall cost saving of about 24% in the total cost of materials is possible if the materials are used within the immediate environment where the wastes are being generated. 41% cost reduction in mass concrete is the highest cost saving while 12% in plaster mortar is the lowest.

However, overall cost saving is dependent on the distance of the agricultural waste from production or construction site. The discussed results suggest that POS used as granite more than 25km away from dump site may not be economical over crushed granite due to cost of transportation. So also, RHA processed at a distance of more than 50km away from mill site may not be economical. Nevertheless, the cost of having an environment free of pollution from the accumulating waste is however priceless.

In order to reduce the cost of embodied energy of RHA arising from transportation, rice processing mills could be designed to integrate a furnace in the production line. This will allow the ease and immediate processing of RH to RHA as the husk is being generated. Otherwise, to reduce the cost of transport, rice husks can be transported in a compressed form. RH can be compressed to as much as about 500kg/m^3 without destroying their elasticity. So also, government can, or encourage communities, to build kilns or furnaces where the husk is readily available and be used as communal facility.

Residents within 25km vicinity of palm oil mill should be enlighten and encouraged to use OPS as a coarse aggregate to replace crushed granite particularly in lightweight structures such as residential development, foot bridges, walkways etc. The communities should be enlighten on the economic as well as the environmental benefits of utilising rice husk and oil palm shell as partial or complete replacement of the conventional building materials.

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Usman Aliyu JALAM, Abdurrahman Aliyu JALAM, Ibrahim M. SALE and Olurunmeye Fredrick JOB

Oszacowanie kosztów wykorzystania materiałów budowlanych pochodzących z odpadów rolnych jako zrównoważonych materiałów do lekkich konstrukcji

Streszczenie

Rezultaty działań podejmowanych w eksperymentalnych laboratoriach, a także pewne praktyczne przykłady pokazują, że można uzyskać kilka rodzajów materiałów budowlanych z odpadów rolnych. Materiały te mogą być wykorzystane w celu częściowego lub całkowitego zastąpienia konwencjonalnych materiałów budowlanych. Wysiłki te jednak nie zaspokoiły w pełni potrzeby alternatywnych materiałów budowlanych. Wynika to z braku uogólnionych informacji na temat rozwoju materiałów, które najczęściej dotyczą kilku właściwości owych materiałów, ale nie dostarczają znaczących studiów nad ekonomicznymi efektami innowacji. Niniejszy artykuł ma na celu ustalenie, czy wykorzystanie materiałów budowlanych pochodzących z odpadów rolnych przynosi korzyści pieniężne i w jakim zakresie. Oszacowano koszty wykorzystania zwykłego cementu portlandzkiego (ang. Ordinary Portland Cement, OPC), popiołu z łusek ryżowych (ang. Rice Husk Ash, RHA), a także pozostałości po wytłaczaniu oleju palmowego (ang. Oil Palm Shell, OPS) w blokach betonowych i piaskowo-betonowych oraz zaprawie wiążącej i tynku. Koszty oceniono na podstawie aktualnych kosztów materiałów za jednostkę pomnożonych przez aktualną wykorzystaną ich ilość. Badania wykazały, że największa redukcja kosztów wyniosła 41% w odniesieniu do betonu, natomiast najmniejsza – 12% w odniesieniu do tynku. Ogólna oszczędność kosztów wyniosła około 24% całkowitych kosztów materiałów. Jednak wyniki ukazały również, że ogólna oszczędność kosztów zależy od odległości, w jakiej znajdują się odpady rolne w stosunku do miejsca produkcji lub budowy. Jako najważniejsze wyzwanie uznano brak łatwo dostępnej i odpowiedniej technologii przetworzenia niektórych odpadów rolnych w materiały budowlane.

***Słowa klucozwe*: koszt, odpady rolne, zrównoważone materiały budowlane, lekkie konstrukcje**

Appendix I. The Control Gazebo.

Source: Photograph taken by the authors.

Appendix II: The Treatment Gazebo.

Source: Photograph taken by the authors.