Appraising the Environmental Friendliness of Rice Husk Ash and Oil Palm Shell as Building Materials from Agricultural Waste

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Abstract

The biggest challenge with concrete as the most expensive basic construction material made from cement and aggregate is that of creating a balance between economic constraints and environmental considerations with performance as the focal point. An appraisal of the environmental friendliness of Rice Husk Ash (RHA) and Oil Palm Shell (OPS) as emerging alternative building materials from agricultural waste to supplement and replace conventional cement and coarse aggregates in the production of concrete was conducted in order to guide their appropriate selection and utilisation. The embodied energy accrued during the production of RHA and OPS were assessed and compared with that of Ordinary Portland Cement (OPC) and crushed granite as coarse aggregate. Building Materials Green Feature Assessment criteria of Leadership in Energy and Environmental Design (LEED) was adopted in assessing the green features of both the materials. The appraisal concluded that the production processes and the behaviour of the materials at the construction and post construction stages were found not to have any significant negative impact on the environment in terms of pollution, resources depletion and ecological disturbance. The materials contain less embodied energy than the conventional materials i.e. OPC and coarse aggregate. There is however, the need to develop the necessary appropriate technologies for the local harnessing and utilisation of these emerging materials.

Keywords: *Rice-Husk-Ash, Oil-Palm-Shell, Green Features, Agricultural Waste.*

Introduction

Undoubtedly, the building industry is known as a high resource consumption user of raw material, energy and usage of land (Ahankoob, 2013). Building materials requiring sophisticated processing, particularly concrete, has gained wide acceptability and has subsequently became a major and widely used building material in construction of buildings (Job, 1998; Arayela, 2002; and Duggal, 2012).

Concrete, as a building material, is a non-homogenous manufactured stone composed of graded granular inert materials (aggregates) held together by the action of cement and water (Job, 1998). Duggal (2012) opined that the major factors responsible for the wide usage of cement-concrete are mouldability, early hardening, high early compressive strength, development of desired properties with admixtures to be used in adverse situations, suitability for guniting, pumpability and durability.

Consequently the demand for cement and coarse aggregates which occupies more than half of the volume of concrete (Neville, 1981), became high. This made concrete production and in general concrete works, gradually becoming prohibitive majorly due to increasing costs of the binder (cement) and coarse aggregate (Kamang & Bingila, 2000). Bustani, Kunya, Mua'zu, Mohammed and Owoyale (2002) reported that cement has been identified as the most expensive component of concrete. This has generally been attributed to sophisticated production process requiring very high embodied energy, high transportation costs of these materials, demand and environmental restrictions (Okoli, 1998; Job, 1998; Kamang & Bingila, 2000; Dashan & Nwankwo, 2000; Arayela, 2002; Jinadu, 2004; Odunjo, Adeoye, & Oyadokun, 2006; Pappu, Saxena & Asolekar, 2007; Jalam & Damagum, 2007). Arayela (2002) further reported that local production of cement has grossly failed to meet the national demand since 1975 in Nigeria.

Although cement has been accepted as a vital material in construction today, it has as well been a silent culprit of creating imbalances of the environment. For instance, for every tonne of cement produced, as much as 1.25 tonne of carbon dioxide (CO_2) (greenhouse gas) is released by the burning fuel, and an additional 1.25 tonne is released in the chemical reaction that changes raw material to clinker, making the production of cement responsible for more than 8% of all the greenhouse gases released by human activity (Osha, Aroke & Aliyu, 2005). So also, today, our construction projects typically consume large amount of materials with a very high embodied energy, and produce tonnes of waste most of which is disposed of in landfills constituting up to about 20 – 30% of the volume of landfills (Gordon, 1999).

The biggest challenge with concrete as the most expensive basic construction material is therefore that of creating a balance between economic constraints and environmental considerations with performance as the focal point. The evaluation of the sustainability of emerging alternative building materials to replace and supplement aggregates and cement in the production of concrete has therefore become necessary in order to guide their appropriate development, selection and utilisation as more sustainable building materials than the conventional materials.

Green Building Materials/ Assessment Tools

Ahankoob (2013) noted that the remarkable growth in the advanced construction techniques characterised by excessive use of resources such as water, materials, energy and fossil fuels on a global scale, has intensified significantly the needs for having sustainable buildings. Sustainable buildings are only possible when they are built with green materials. Jain (2008) described Green Building Materials (GBM) as those building materials obtained from natural renewable sources that have been managed and harvested in a sustainable way; or they are obtained locally to reduce the embodied energy or salvaged from reclaimed materials.

Green materials are environmentally responsible because they are usually assessed using green specifications that look at their Life Cycle Analysis (LCA) in terms of their embodied energy, durability, recycled contents, waste minimisation, and their ability to be reused or recycled. Consequently, many countries have taken notable steps in identifying, assessing and utilising GBMs. These steps have led to introducing sustainable assessment tools. In this regard, many countries have provided appropriate strategies to prevent the excessive consumption of materials' situation from getting worse.

Building Research Establishment (BRE) in England took the pioneer steps in 1990 by establishing the Building Research Establishment Environmental Assessment

Methodology (BREEAM). BREEAM is the world's longest established method of assessing, rating, and certifying the sustainability of buildings and building materials. This was followed in 1996 by the United States Green Building Council's Leadership in Energy and Environmental Design (LEED) (Ahankoob, 2013). LEED is a third party certification programme and approved as a benchmark in the world. This programme provides a clear direction for various phases in a project including design, construction and operation of buildings.

According to Ahankoob (2013), assessment tools in the past were primarily used to measure specific concepts of green methodology. The focus area was selected to address key aspects of inefficiencies in buildings. Most tools focused on three main areas: energy, material and water use in the building. In recent years, new sustainable practices were applied such as: day lighting analysis, native plants, material re-use, recycle and densification.

As at 2014, World Green Building Council (WGBC) as an alliance of Green Building Councils has as allies, eighty (80) Green Building Councils worldwide and serves as the largest international organisations that influence the green building market place (Bahaudin, Elias & Saifudin, 2014). Ahankoob (2013) and Bahaudin *et al.* (2014) reported some of the established criteria and rating systems around the world as: BREEAM (U.K.), LEED (U.S.A.), Green Star (Australia and New Zealand), Green Building Index (GBI) (Malaysia), Green Mark (GM) (Singapore), Korean Green Building Certification Council (KGBCC) (South Korea), Compressive Assessment System for Built Environment Efficiency (CASBEE) (Japan), and Green Ship (GS) (Indonesia).

Others include: Green Building Council Australia (GBCA) (Australia), AQUA/LEED (Brasil), Green Globes (GG) (Canada), PromisE (Finland), High Quality Environment (HQE) (France), *Deutsche Gesellchalt fur Nachhaltiges Bauen* (German Sustainable Building Council, DGNB) (Germany), Minergie (Switzerland), BREEAM Netherland (Netherland), and EDAMA (Jordan).

A closed comparison of the various councils revealed that each council employ at least five (5) of the following criteria for assessment: Energy Efficiency, Water Efficiency, Indoor Environment Quality, Site Planning and Management, Innovation, Materials and Resources, Environmental

Protection, Transport, Land Use and Ecological Environment. Singapore's GM has the least criteria of five (5) while South Korean KGBCC has the most stringent criteria of nine (9) elements.

Each of these programmes ultimately lead to a certification which requires precise fulfilment of all terms and processes stipulated in the programme's documents. However, both studies by Ahankoob, (2013) and Bahaudin *et al.* (2014) agreed that LEED is becoming the standard by which many green buildings are measured. LEED quantifies a building's performance in the following major categories as shown in Table 1.

Table 1: LEED Scoring and Rating Award for New Construction Building & Major Renovations

Criteria	Scoring
Energy and Atmosphere	17
Water Efficiency	5
Sustainable Sites and Transportation	14
Indoor Environment Quality	15
Material and Resources	13
Innovation & Design Process	5
Total	69

Source: Bahaudin *et al.* (2014).

According to Bahaudin *et al.* (2014), LEED takes a much broader "triple bottom line" approach considering people, planet and profit, not just energy use. The triple bottom line factors in the economic, environmental and social issues are present throughout the entire building process from concept, design, development and future operation. It has however been concluded that, the only criterion that has relevance to the pre-operational stage of a building is Materials and Resources where emphasis is on recycled, reused sustainable materials and green products during the construction phase.

Materials and Methods

The study adopted a quantitative research approach involving experimental and comparative analysis. The materials for the study were Ordinary Portland Cement (OPC), crushed granite as coarse aggregate, Oil Palm Shell (OPS) and Rice Husk Ash (RHA). Ibeto brand of Ordinary Portland Cement (OPC) Type I (ASTM C-150) (2007) of strength class 42.5N was used throughout the study. Crushed natural stone with a maximum nominal size of 19mm obtained from local building materials sellers was used as coarse aggregate.

The OPS aggregates were obtained at local palm oil mills from Ette in Enugu State, Wamba and Lafiya towns of Nasarawa State in the south-east and north-central parts of Nigeria respectively. Transport cost of $1m^3$ of the OPS per kilometre from the source of the OPS to site was recorded. The RHA used was from a locally sourced rice-husks (RH) burnt in a kiln of the Ceramics Section of Department of Industrial Design, Abubakar Tafawa Balewa University Bauchi. The RH was burnt under a controlled temperature of 700°C and was later pulverised according to the Indian Standards for Pozzolana 1344 (2000). 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 embodied energy contributors in OPC and coarse aggregate were assumed to have been covered in their cost per m^3.

Building Materials Green Feature Assessment criteria of Leadership in Energy and Environmental Design (LEED) was adopted in assessing the green features of both the conventional materials (cement and coarse aggregate) and the derived materials (OPS and RHA). LEED assessment criteria was adopted over other assessment criteria because, while most tools focused on three main areas: energy, material and water use, LEED's assessment criteria covers the entire life cycle of a building material: from manufacturing process through building operations to post building management. So also, it has been in use since 1996 and has been adopted by several countries than any other assessment criteria as reported by Roux and Alexander (2007) and Jain (2008).

Results

The cost of $1m^3$ of OPC was found to be ₦63, 370: 00 while ₦6, 667:00 was recorded as the cost of $1m^3$ of crushed granite coarse aggregate. These represent the monetary value of the embodied energy in OPC and coarse aggregate respectively. Table 2 presents the result of the embodied energy contributors assessment of $1m^3$ of OPS. The only major contributor is the transportation of the OPS from point of generation to the point of utilisation. It can be seen that it cost ₦270: 00 to transport 1m3 of OPS over a distance of $1m^3$. Other activities involved in the processing stages, sieving and weathering do not actually accrued any significant energy. The weathering was done naturally by exposing the shells to weather elements while it was sieved manually.

Table 2: Embodied Energy Contributors of $1m^3$ of OPS.

Item	Value
Transport Cost/Km (Naira)	₦270: 00/km
Sieving	-
Weathering	-
POS Obtained (Kg)	$1m^3$

Table 3 shows the embodied energy contributors analysis of obtaining RHA from $1m^3$ of rice husk. The table shows that the major contributors are transportation and kiln fuel. It costs ₦220: 00 to transport

1m^3 of rice husk over 1km. As much as 57.6 litres of kerosene was used as kiln fuel to burn 1m^3 of rice husk. The cost of the fuel was ₦2, 880: 00. The total RHA obtained from 1m^3 of rice husk was 0.18m^3.

Table 3: Embodied Energy Contributors of Processing 1m^3 of RH to RHA.

Item	Data
Transport Cost/Km (Naira)	₦220: 00/km
Kiln Fuel (Litre/Cost)	57.6 litres (₦ 2, 880: 00)
Ash Obtained (m^3)	0.18

Table 4 presents the critical assessment of OPC as a green building material when subjected to the LEED's assessment criteria. OPC satisfied most criteria during building operations. It can be seen from the table that during the manufacturing process, OPC was found to satisfy only one criterion. However, OPC satisfied three and one criteria during the building operations stage and waste management/post building stage respectively. A total of five green features criteria were satisfied by OPC.

Table 4: Green Features Assessment of OPC

Green Features		
Manufacturing Process (MP)	Building Operations (BO)	Waste Management/Post Building (WM)
Waste Reduction (WR)	Energy Efficiency (EE) √	Biodegradable (B)
Pollution Prevention (P2)	Water Treatment/C onservation (WTC)	Recyclable (R) √
Recycled (RC)	Nontoxic (NT) √	Reusable (RU)
Embodied Energy Reduction (EER)	Renewable Energy Source (RES)	Others (O)
Natural Materials (NM) √	Longer Life (LL) √	

√ = Applicable.

Table 5 presents the critical assessment of crushed granite aggregate as a green building material. Crushed granite satisfied most criteria during the manufacturing process. It can be seen from the table that during the manufacturing process, crushed granite was found to satisfy three out of five criteria. However, crushed granite satisfied only two and one criteria during the building operations stage and waste management/post building stage respectively. A total of six green features criteria were satisfied by crushed granite.

Table 5: Green Features Assessment of Crushed Granite Aggregate

Green Features					
Manufacturing Process (MP)		Building Operations (BO)		Waste Management/Post Building (WM)	
Waste Reduction (WR)	√	Energy Efficiency (EE)		Biodegradable (B)	
Pollution Prevention (P2)		Water Treatment/Conservation (WTC)		Recyclable (R)	√
Recycled (RC)	√	Nontoxic (NT)	√	Reusable (RU)	
Embodied Energy Reduction (EER)		Renewable Energy Source (RES)		Others (O)	
Natural Materials (NM)	√	Longer Life (LL)	√		

√ = Applicable.

Table 6 presents the critical assessment of RHA as a green building material. RHA satisfied all the criteria during the manufacturing process. It can also be seen from the table that during the building operations stage, RHA was found to satisfy eighty percent of the criteria. So also, RHA satisfied two out of the four criteria during the waste management/post building stage. A total of ten green features criteria were satisfied by RHA.

Table 6: Green Features Assessment of RHA.

Green Features					
Manufacturing Process (MP)		Building Operations (BO)		Waste Management/Post Building (WM)	
Waste Reduction (WR)	√	Energy Efficiency (EE)	√	Biodegradable (B)	
Pollution Prevention (P2)	√	Water Treatment /Conservation (WTC)		Recyclable (R)	√
Recycled (RC)	√	Nontoxic (NT)	√	Reusable (RU)	√
Embodied Energy Reduction (EER)	√	Renewable Energy Source (RES)	√	Others (O)	
Natural Materials (NM)	√	Longer Life (LL)	√		

√ = Applicable.

Table 7 presents the critical assessment of OPS as a green building material. OPS satisfied all the criteria during the manufacturing process. It can also be seen from the table that during the building operations stage, OPS was found to satisfy eighty per cent of the criteria. However, OPS satisfied only two out of the four criteria during the waste management/post building stage. A total of eleven green features criteria were satisfied by OPS.

Table 7: Green Features Assessment of OPS.

Green Features		
Manufacturing Process (MP)	Building Operations (BO)	Waste Management/Post Building (WM)
Waste Reduction (WR) √	Energy Efficiency (EE) √	Biodegradable (B)
Pollution Prevention (P2) √	Water Treatment/Conservation (WTC)	Recyclable (R) √
Recycled (RC) √	Nontoxic (NT) √	Reusable (RU) √
Embodied Energy Reduction (EER) √	Renewable Energy Source (RES) √	Others (O)
Natural Materials (NM) √	Longer Life (LL) √	

√ = Applicable.

Discussion

From Table 6, the relative Green Features of RHA is 71.43% as against about 36% for OPC (Table 4). RHA can be seen to be relatively about twice greener than OPC. This can be attributed to the fact that the manufacturing process of RHA requires no engagement in a mining or manufacturing process that generates air pollution, water pollution or erosion. The manufacturing process (burning at controlled temperature of about 700°C) when basket-burner is used, does not depletes the world's reserves of fossil fuels and greatly reduces the depletion of fossil fuels in relation to cement when kiln is used (Allen, 2010). Neither does it leave behind, waste of any sort. So also, rice husk does not require any shredding, hammer-milling, fluffing, fiberising, binding or stabilising in the burning process to obtain ash. Indeed, the most significant cost associated with the utilisation of the rice husk in the production of its ash is its transport from point of generation to the point of burning. Additional challenge associated with the processing of RH to

RHA in Nigeria is the cost of burning the husk into pozzolanic material due to lack of furnaces and kilns.

From Table 3, 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 ₦220: 00/km. That is to say ₦1, 222: 00 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. This confirms the earlier findings of Velupillai, Mahin, Warshaw and Wailes (1996) that RHA possess, surely in those areas where the husks are available, far less embodied energy than OPC. But the on-site cost of $1m^3$ of OPC is ₦63, 370: 00. 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. So also, while in use, RHA was found to be non-toxic and last as long as OPC does (Chunsangunsit, Gheewala & Patumsawad, 2004).

Although Velupillai *et al.* (1996), Chungsangunsit *et al.* (2004), Prasara-A and Grant (2008) and Chungsangunsit, Gheewala and Patumsawad (2009) confirmed that RH can be used as a fuel to generate electric power capable of providing substantial savings, Oliveira *et al.* (2012) reported that photo-oxidant formation during the burning of the RH is higher due to high CO emission. Furthermore, the ash from this process is disposed of as it is not pozzallanic due to high carbon content. In the same vein, Oliveira *et al.* (2012) further reported that when considering only the electricity production and comparing the impact potential categories results with the conventional fuels, it is seen that rice husk is an environmentally friendly fuel for global warming, acidification and nutrient enrichment.

So also, of all cereal by-products, the RH has the lowest percentage of total digestible nutrients of less than 10% (Juliano, 1985). Similarly, RH, though an organic material, is also resistant to the best efforts of man to dispose of it due to the very high percentage of silica in combination with large amount of phenyl propanoid structural polymer called lignin (Allen, 2010). However, RHA: OPC concrete products can be recycled just like the OPC concrete products. Consequently, Prasara-A and Grant (2008) concluded that of all the identified alternative uses of RH such as brick production, briquette production, waste water treatment plant, agricultural industry and cellulosic ethanol production, the most environmentally favourable rice husk use in comparison with all other rice husks use systems, is the use in cement manufacture.

On the other hand, Portland cement is not an environmentally friendly material; its manufacture creates greenhouse gas emissions; and, it also reduces the supply of limestone (Naik, 2005; Osha, Aroke, & Aliyu, 2005). Zeobond (2012) reported that "OPC is made primarily of 60% CaO, 40% SiO_2 and some Al_2O_3, Fe_2O_3 and SO_3. The source of calcium is limestone, which is mainly calcium carbonate ($CaCO_3$), and is obtained through quarrying. In manufacturing a tonne of OPC approximately 0.60 tonne of CO_2 from the $CaCO_3$ $CaO + CO_2$ calcination reaction is produced. In addition, approximately 0.40 tonne CO_2 is produced from fossil fuels used to generate the energy to heat the materials to 1400°C. In total the manufacture of a tonne of OPC therefore emits approximately 1 tonne Co_2."

Green Features assessment of OPS presented on Table 7 indicates a relative Green Feature of about 79% as against 50% of crushed granite. OPS is a natural material and does not require any further processing before being used as aggregate other than sieving and weathering. The process of sieving does not pollutes the environment. The only waste being generated during this process, are particles of the shell smaller than 5mm. This waste can be used to harden road surfaces within the palm oil plantation with no negative impact to the environment.

Transporting the OPS from the point of generation to the point of utilisation could therefore be the only contributor to the OPS's embodied energy. As shown in Table 2, it cost about ₦270: 00 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 ₦6, 667: 00. 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 ₦6, 667: 00/m^3.

Azali, Nasrin, Chao, Adam and Sapuan (2005) reported that oil palm fibre and shell can be used as boiler fuel to generate steam in palm oil mill and suggested that the oil palm ash (OPA) obtained from this process could be pozzalanic. Other studies on the alternative use for OPS show that most biomass waste from palm processing can be composted and be used as organic fertilizer. Unfortunately, the shell has the least nutrient content of N = 3.0%, P = 0.1%, K = 0.8%, Mg = 0.2% and Ca = 0.2% (Sahari & Maleque, 2016). More so, the shell does not compost due to the presence of fibrous materials (Oviasogie, Odewale, Aisueni, Eguagegie, Brown & Okoh-Oboh, 2013). However, Teo *et al.* (2006); Rukzon and Chindaprasirt (2008); and Chindaprasirt, Rukzon and Sirivivatnanon (2008) confirmed that OPA is not as pozzalanic as RHA. Teo *et al.* (2006) concluded that the best utilisation of OPS is as aggregate in construction in which no further processing is required.

Putting crushed granite into focus, some of the environmental disturbance created by quarrying of granite to obtain crushed granite as aggregate is caused directly by engineering activities during aggregate extraction and processing. Langer (2001) identified change in geomorphology and conversion of land use, with the associated change in visual scene as the most obvious engineering impact of quarrying. This major impact is usually accompanied by loss of habitat, noise, dust, vibrations, chemical spills, erosion, sedimentation, and dereliction of the mined site (Langer, 2001).

Conclusion

The manufacturing process of RHA requires no engagement in a mining or manufacturing process that generates air pollution, water pollution or erosion. The manufacturing process (burning at controlled temperature of about 700°C) does not depletes the world's reserves of fossil fuels neither does it leave behind, waste of any sort. The significant contributor to the embodied energy of RHA is the transportation of the RH from point of generation to the point of burning.

OPS is a natural material and does not require any further processing before being used as aggregate other than sieving and weathering. The process of sieving and weathering does not pollutes the environment. The only waste being generated during these processes, are particles of the shell smaller than 5mm. This waste can be used to harden road surfaces within the palm oil plantation with no negative impact to the environment. Transporting the OPS from the point of generation to the point of utilisation is the only significant contributor to the OPS's embodied energy.

RHA and OPS are natural materials and their production processes were found not to have any significant negative impact on the environment in terms of pollution, resources depletion and ecological disturbance. The materials contain far less embodied energy than the conventional materials. From the point of view of the three dimensions of sustainability, i.e. environmental; economic; and social, the study can conclude that RHA and OPS are more sustainable than OPC and crushed granite. Their relative sustainability is however, dependent on the distance between point of generation of the waste and the point of utilisation as building materials. OPS used as aggregate 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. Hence, adopting these materials will strike a balance between environmental considerations and economic constraints which will subsequently address the issue of cost of building materials as a militating factor in construction, particularly housing provision.

Recommendations

i. Rice and oil palm producing communities should be enlighten on the economic as well as the environmental benefits of utilising RH and OPS as partial or complete replacement of OPC and crushed granite.

ii. 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 while people residing within 50km of the vicinity of a rice mill will find it difficult to explain their inability to supplement cement with RHA.

iii. 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 and effect of transport, rice husks can be transported in a compressed form. RH can be compressed to as much as about 500kg/m^3 as against transporting it in its loose density of 455kg/m^3.

iv. So also, government can, or encourage communities, to build kilns or furnaces where the husk is readily available and be used as a communal facility.

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