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The Evaluation of Oil Palm Residue (*Palm Kernel Shells And Fibers*) as an Essential Sustainable Construction Material in the Niger Delta Region

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ABSTRACT

This paper investigates the innovative use of oil palm residues, specifically palm kernel shells (PKS) and fibers, as sustainable building material in the Niger Delta region of Nigeria. By examining the material properties, its characteristics, availability, and application of the residues as well as what makes it sustainable, the study underscores the potentials in contributing to affordable and eco-friendly housing solutions in terms of material options. The research method adopted in this research is qualitative research, particularly secondary qualitative research and content analysis. The paper delves into the environmental benefits of repurposing these waste products and presents their application in light weight concrete, composite materials, and modular construction. This approach x-rays pathways to both environmental waste management and an answer to housing shortages by use of cheap and affordable ecofriendly materials in the Niger Delta.
Keywords: Oil palm residues, Palm Kernel shells and fibres, Niger Delta

INTRODUCTION

The Niger Delta, a major hub for oil palm production, generates vast quantities of waste in the form of palm kernel shells (PKS) and palm fibers. Despite their potential, these residues remain underutilized, contributing to environmental waste. However, the increasing demand for affordable housing provides an opportunity to repurpose these by-products for sustainable construction. Previous studies (Olanipekun et al., 2006; Shafigh et al., 2014) have shown that PKS and palm fibers can serve as valuable alternatives to traditional construction materials, especially in developing regions. This paper explores the potential of oil palm residues in the construction industry, focusing on their properties and applications in the context of sustainable housing.

Constituents and Properties of Oil Palm Residues

Palm Kernel Shells (PKS)

PKS are a by-product of palm oil extraction and are characterized by their hard, lignocellulosic structure, making them suitable for use as aggregates in concrete.

Studies show that PKS have a bulk density of 500-600 kg/m^3 (Basri et al., 1999), making them ideal for lightweight construction. Additionally, their low ash content and high thermal stability make them environmentally friendly substitutes for traditional construction materials. PKS have a high resistance to abrasion, and their relatively low crushing value (about 20%) suggests they are durable for use in construction (Teo et al., 2007).

Palm Fibers

Palm fibers, derived from the mesocarp of the palm fruit, are known for their high tensile strength and flexibility. With a density of about 1.2 g/cm^3 and high resistance to moisture absorption, these fibers have shown promise in reinforcing cementitious materials (Abdul Khalil et al., 2011). Their physical properties can improve the tensile strength and durability of concrete, making them suitable for use in composite panels and modular structures (Abdullah et al., 2011).

Mechanical Characterization

The mechanical characterization of palm kernel shell consists here of determining the longitudinal Young's modulus, the fish coefficient and the impact energy.
The species of interest are DURA and TENERA. All palm kernel shells are obtained from mature nuts from the same cob for each species.

Density

The determination of the density parameters of the materials indirectly provides an approximation of the quality of their constructive properties.

Absolute Density

The absolute density is determined experimentally by the pycnometer method according to NF P 94-054. The procedure used consisted in carrying out the following operations:

- Select a sample and place it in the oven at 105°C for 24 hours.
- Weigh a pycnometer filled with distilled water to the mark and note its mass M1.
- Weighing a sample of aggregate of mass M2.
- Introduce the sample into a pycnometer after pouring in a quantity of water.
- Gradually fill the pycnometer up to the mark, eliminate air bubbles and note M3 its mass.
- Note the temperature of the water in the pycnometer.

The values of the individual weights are used to determine the absolute density.

$$\rho_{abs} = \rho_e \cdot M_2 / \left[(M_1 + M_2) - M_3 \right]$$

where ρ_e is water density taken conventionally

Source: Ndapeu, (2020)

Apparent Density

The bulk density was determined by the hydrostatic balance method according to the recommendations of NF P 94-053. The principle of the method consists in determining the volume of a sample by means of the Archimede thrust. It is obtained from successive weighing of the sample. Samples are taken by the quartage
method and weighed on a 10−3 g precision scale.

- Let methe mass of the sample, then the sample is immersed in previously melted paraffin.
- Let m_{e+p}, the mass of the sample plus paraffin (with a density of 0.87796 g/cm^3)

The wax sample is then carefully immersed in water.

○ The displaced volume of water V_d is given by the expression $V_d = V_e + V_p$

○ The volume of the paraffin is: $V_p = \dfrac{m_{e+p} - m_e}{\rho_p}$

○ The volume of the sample is given by the relationship $V_e = V_d - V_P$

The bulk density is expressed as the ratio of the mass of the sample to the volume of the sample.

$$\rho_{ap} = \frac{m_e}{V_e} \quad (2)$$

Source: Ndapeu, (2020)

Porosity (*p*), Void Index (*e*) and Compactness (*c*)The dimensionless characteristics, given by Equations (3), (4) and (5), provide information on the voids in a body

$$e = \frac{\rho_{abs} - \rho_a}{\rho_a} \quad (3)$$

$$p = \frac{e}{e+1} \quad (4)$$

$$c = 1 - P \quad (5)$$

Density of PKS

The density of the palm kernel shell is given in Table 2 below. This result shows that palm kernel shells of the species TENERA are more porous than those of the species DURA. This is not due to their parameters of cultivation or area of production. But fundamentally, this is attributable to their microstructure with and important porous network.

Resilience Energy of PKS

The average impact energy of palm kernel shell is 2.066 J/cm2 and 1.894 J/cm2for DURA and TENERA species respectively at a temperature of 26°C. It is clear that DURA PKS are more resistant to breakage. This resistance is directly linked to the highest density, compactness and low void index of Dura variety. Moreover, their structure and thickness are considerable. We also note that the resilience energy of the palm kernel shell decreases linearly with a correlation coefficient R2 of 0.914 with increasing temperature. It varies between 1.63J/cm2 at 50°C and 0.58 J/cm2 at 90°C as shown in Figure 4 below.

Young Modulus of PKS

The Young's modulus of the palm kernel shell of the DURA variety is 19 GPa and that of the TENERA variety is 17.9 GPa at a temperature of 26°C. Figure 5 below shows the variation in deflection as a function of load with a correlation coefficient R2 of 0.9956. In Table 3, we find that palm nut shells have a density close to that of coconut

Source:Ndapeu,

Table 2. Void index, porosity, compactness and density values.

SPECIES	DURA	TENERA
Apparent density (Kg/m^3)	1370	1174
Absolute density (Kg/m^3)	1428.81	1395.81
Void index (e)	0.043	0.188
Porosity (p)	0.041	0.158
Compactness (c)	0.958	0.841

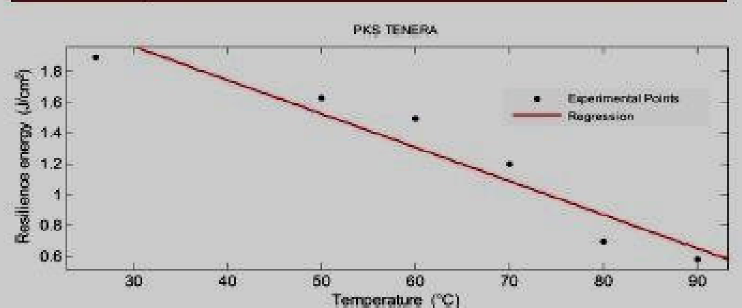

Figure 4. Impact enregy vs. temperature.

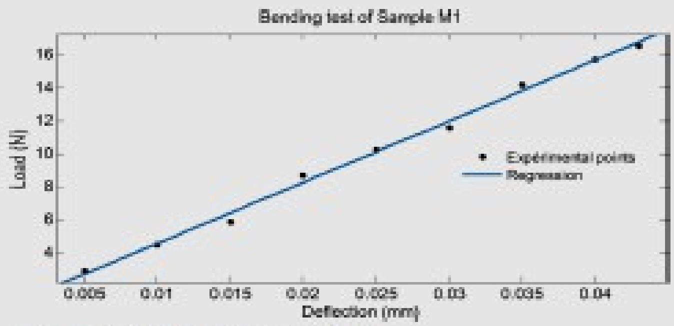

Figure 5. Variation of deflection with load.

Table 3. Comparison of absolute density and Young's modulus of some wood species.

Wood species	Absolute Density (Kg/m³)	Young Modulus (Gpa)	References
ACAJOU	500 - 680	9.5	[2]
AFROMASIA	650 - 800	10.6	
AZOBE	1000 - 1100	17.3	
BILINGA	730 - 890	11.8	
BOSSE	600 - 700	10.8	
BIBINGA	750 - 950	16.3	
CELTIS	620 - 900	13.5	
DOUSSIE	700 - 880	13.7	
EBIARA	600 - 800	10.4	
EKABA(EKOP)	500 - 750	11.7	
GHEOMBI	650 - 800	15	
GOMBE	570 - 690	11.6	
IROKO	550 - 750	10.3	
KANDA	700 - 760	12.4	
KOSIPO	600 - 780	9	
LATI	700 - 880	13.2	
LIMBALI	730 - 880	14.5	
LONGHI	700 - 800	14.7	
MAKORE	600 - 750	11.2	
MANSONIA (BETE)	600 - 700	11	
MOABI	800 - 900	17	
SAPELLI	600 - 780	11.3	
Coconut shell	1293	11.9	[1]
Palm kernel shell TENERA	1395	17.9	Present work
Palm kernel shell DURA	1428	19.03	Present work

Source: Ndapeu, (2020)

Availability and Environmental Impact

The Niger Delta produces significant quantities of PKS and palm fibers annually, which often go unused and contribute to environmental pollution. Utilizing these residues in construction not only reduces waste but also promotes carbon footprint reduction (Onwuka et al., 2019). Additionally, the conversion of oil palm waste into construction materials supports the global push for sustainable practices in the building industry (Safiuddin et al., 2011).

Innovative Applications in Construction

Palm Kernel Shells in Lightweight Concrete

PKS can be processed to replace traditional aggregates in concrete production. The resulting PKS- based concrete is lighter in weight, improves thermal insulation, and reduces transportation costs due to its lower density. PKS-based lightweight concrete has been found to exhibit compressive strengths between 17 and 23 MPa, making it suitable for low-cost residential buildings (Olanipekun et al., 2006). Furthermore, it has been shown to provide enhanced fire resistance compared to conventional materials (Okafor, 1988).

Fibers in Composite Panels Palm

Palm fibers can be integrated into cementitious materials to produce eco-friendly composite panels. These panels, which have higher tensile strength and lower density, can be used in partition walls, ceilings, and roofing sheets (Abdullah et al., 2011). By using these fibers as reinforcements, the strength of composite materials is increased while cracking is reduced, making them more durable and energy-efficient (Safiuddin et al., 2011).

Hybrid Systems

A hybrid approach, utilizing both PKS and palm fibers, offers multifunctional properties that combine the strengths of each material. This approach enhances the structural performance of lightweight concrete and increases the thermal and acoustic insulation properties of building elements (Shafigh et al., 2014).

Construction Techniques and Implementation

On-Site Casting

PKS-based concrete can be easily cast on-site for constructing walls, floors, and other structural elements. Due to the lightweight nature of PKS, the need for heavy equipment is minimized, which is particularly beneficial in remote areas with limited access to construction machinery (Teo et al., 2007).

Prefabrication

Prefabricated panels using oil palm residues can be manufactured off-site and transported to the construction location. This method ensures quality control and reduces on-site waste, while significantly speeding up the construction process (Shafigh et al., 2014).\

Economic and Social Implications

Cost-Effectiveness

Using locally available PKS and palm fibers lowers construction costs by reducing the reliance on expensive conventional materials. PKS concrete, for example, has been shown to be significantly cheaper to produce than conventional concrete, making it a viable option for low-income housing (Olanipekun et al., 2006).

Employment Opportunities

The processing and utilization of oil palm residues in construction can generate employment opportunities in local communities, fostering economic growth. These opportunities extend to the collection, processing, and distribution of PKS and fibers for construction purposes (Onwuka et al., 2019).

Challenges and Solutions

Technical Challenges

One of the key challenges in using PKS and palm fibers in construction is ensuring uniformity in material quality. Variations in the size, density, and moisture content of PKS and fibers can affect the performance of the final product.

Solutions

Solutions to these challenges include material treatment methods such as drying, grading, and surface treatment to enhance the properties of PKS and fibers. Research and standardization efforts are needed to develop guidelines for the use of these materials in sustainable construction (Bamigboye et al., 2016).

Compressive Strength of Oil Palm Residue Materials in Construction

Here is a visual representation comparing the compressive strength of palm kernel shells (PKS) and palm fibers. Since palm fibers are not typically measured for compressive strength, they are represented as 0 in this context, while PKS shows an average compressive strength of 20 MPa. Let me know if you'd like further visualizations or adjustments!

1. **Bamboo**

- **Properties**: Bamboo is highly renewable and grows rapidly. It is known for its high tensile strength, which is even comparable to steel.

- **Applications**: Used in construction for scaffolding, flooring, walls, and roofing. Bamboo is also utilized in green building frameworks.
- **Advantages**: It absorbs CO_2, making it a carbon-negative material. Bamboo is lightweight yet durable.

2. Hempcrete

- **Properties**: Hempcrete is a biocomposite material made from the inner woody core of the hemp plant mixed with lime. It is highly insulative and has excellent thermal and acoustic properties.
- **Applications**: Used for wall insulation, non-load-bearing walls, and infill material for timber- framed buildings.
- **Advantages**: Hempcrete is breathable, resistant to mold, and offers carbon sequestration benefits during its growth cycle.

3. Recycled Steel

- **Properties**: Steel is 100% recyclable without losing its properties. Recycled steel retains its strength, durability, and malleability.
- **Applications**: Used in structural frameworks, roofing, and building facades.
- **Advantages**: Reduces the demand for virgin steel production, which is energy-intensive and contributes to greenhouse gas emissions.

4. Recycled Plastic

- **Properties**: Made from repurposed plastic waste, this material can be molded into different shapes and sizes. It is lightweight and durable.
- **Applications**: Used for creating bricks, tiles, and as insulation material.
- **Advantages**: Helps reduce plastic waste and is low maintenance and resistant to corrosion.

5. Straw Bales

- **Properties**: Straw bales are excellent insulators and have a high R-value (thermal resistance). They are renewable and biodegradable.
- **Applications**: Used in building walls, especially in temperate and cold climates.
- **Advantages**: Straw bale construction provides natural insulation, regulates indoor humidity, and is energy-efficient.

6. Rammed Earth

- **Properties**: Rammed earth is a mixture of earth, sand, clay, and sometimes a small amount of cement, which is compacted to form solid walls.
- **Applications**: Used for walls and foundations. It is especially popular in hot and dry climates.
- **Advantages**: It has excellent thermal mass properties, providing natural temperature regulation in buildings. It is also a low-carbon material when sourced locally.

7. Cork

- **Properties**: Cork is harvested from the bark of cork oak trees, which regenerate after harvesting. It is lightweight, flexible, and has good thermal and acoustic insulation properties.
- **Applications**: Used for insulation, flooring, wall panels, and acoustic treatments.
- **Advantages**: Cork is renewable, biodegradable, fire-resistant, and has excellent insulating properties.

8. Mycelium

- **Properties**: Mycelium, the root structure of fungi, can be grown into various shapes and forms. It is biodegradable and can be used as a foam-like material.
- **Applications**: Used in insulation, packaging, and lightweight structural elements.
- **Advantages**: Mycelium is renewable, biodegradable, and can be grown in controlled environments, making it a sustainable alternative to synthetic materials.

9. Recycled Glass

- **Properties**: Recycled glass can be used in various forms, from crushed glass in concrete to glass tiles and insulation.
- **Applications**: Used in decorative elements, countertops, and as an aggregate in concrete.
- **Advantages**: Reduces the need for new raw materials and energy consumption associated with glass production.

10. Fly Ash Concrete

- **Properties**: Fly ash, a by-product of coal combustion, can be used as a replacement for cement in concrete. This material enhances concrete's strength and durability while reducing the overall carbon footprint.
- **Applications**: Used in building foundations, walls, and bridges.
- **Advantages**: Fly ash reduces the reliance on traditional cement, which is a significant source of CO_2 emissions. It also improves the workability and longevity of concrete.

Comparison of Eco-Friendly Materials

Material	Key Properties	Primary Applications	Environmental Benefits
Bamboo	High tensile, strength, lightweight	Scaffolding, flooring, walls	Renewable,absorbs CO_2, fast-growing
Hempcrete	Insulative, light weight, breathable	Wall insulation, infill for buildings	Carbon sequestration, renewable

Material	Key Properties	Primary Applications	Environmental Benefits
Recycled Steel	Strong, durable, 100% recyclable	Structural frameworks, roofing	Reduces demand for virgin steel production
Recycled Plastic	Lightweight, moldable, durable	Bricks, tiles, insulation	Reduces plastic waste, low maintenance
Straw Bales	High R-value, renewable, biodegradable	Building walls	Natural insulation, energy- efficient
Rammed Earth	High thermal mass, durable	Walls, foundations	Low-carbon, locally sourced
Cork	Lightweight, flexible, insulative	Insulation, flooring, wall panels	Renewable, biodegradable, fire-resistant
Mycelium	Lightweight, foam-like, biodegradable	Insulation, packaging, structural elements	Renewable, biodegradable
Recycled Glass	Decorative, versatile	Countertop, concrete aggregate	Reduces raw material and energy use
Fly Ash Concrete	Enhance strength, reduces cement use	Foundations, walls, bridges	Reduces CO_2 emissions from cement production

Each of these materials has unique properties that make them suitable for sustainable construction and can contribute significantly to reducing environmental impacts, promoting energy efficiency, and lowering construction costs.

CONCLUSION

Oil palm residues, particularly palm kernel shells and fibers, offer a sustainable and innovative solution to the construction challenges in the Niger Delta region. Their use in construction not only addresses the housing deficit but also provides a means for reducing environmental pollution and supporting economic development. Continued research and collaboration between academic institutions, industry stakeholders, and policymakers will be crucial in scaling up the use of these materials in affordable and sustainable housing projects.

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