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Assessment of the Physical and Mechanical Properties of Indigenous Agro-Waste Materials from Southern Nigeria for the Production of Composite Particleboards for Sustainable Building Materials

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Abstract: In this investigation, two varieties of locally produced composite particleboard were investigated. The first kind consists of a mixture of glue, coconut fiber, periwinkle shell, and rice husk. The second kind is an adhesive-sawdust-snail-shell-coconut-fibre mixture. Innovative composite particleboard samples were produced using urea-formaldehyde as an adhesive resin throughout ten (10) runs. The particleboard's moisture content, density, compressive strength, tensile strength, rupture modulus, and elasticity were all assessed. Utilizing the response surface approach, the proportionate mix ratio of the samples (Run 1 to 10) was calculated to choose the samples that best met ASTM and EN (Eurocodes) standards. The study demonstrated that Type A specimens have a more workable outcome than Type B specimens. To meet the specified standard requirements for particleboard production, manual methods must be upgraded or investigated by employing a mechanical approach.

Keywords: composite particleboard; construction materials; sustainable agro-waste materials

1. INTRODUCTION

Particleboard manufacturing for building applications began decades ago in developing countries like Nigeria. It is a composite panel product consisting of cellulosic particles of various sizes bonded together with a synthetic resin or binder under heat and pressure. Particle geometry, resin levels, board density, and manufacturing processes are modified to produce products suitable for specific end uses. Nigeria is an agricultural country with annual wastes of over ten millions ton of agricultural wastes such as rice husk, straw, bagasse, coconut fibre, banana, maize, bean cover, etc. Most of these waste materials are poorly discarded, causing pollution in two primary forms: Discard uncontrolled caused pollution in the canals, riverbanks, and village roads, and burnt caused CO_2 emission to the environment smoked impacted the life of the people [1]. Environmental issues have heightened interest in producing sustainable materials based on renewable resources other than wood, such as agricultural waste. Wheat straw, periwinkle shell, fruit bunch, hazelnut shell and husk, peanut shell, coffee husk, rice husk, rice straw, maize husk, and other agricultural wastes provide a green material supply but also produce a non-food source of economic growth for farming and rural areas. Globally, reducing resource utilization and its environmental impacts is becoming increasingly imperative while maintaining a steady rise in competitiveness. Using recycled resources in production processes instead of new materials usually results in less consumption of energy and original materials, less waste landfilled, and less Green House Gas (GHG) emissions over a product's life cycle [2]. At the same time, this has brought innovation into the production of locally-made particleboards. There is high availability of agro-waste materials, such as timber has been in high demand as a raw material at sawmills, where sawdust is processed in large quantities for use as fuel, filler, and barrier. When properly handled, it is environmentally sustainable, economically very cost-effective, and tends to a state of innovative materials. Also, Rice husk (RH), the hard protective shell of the grain that is the crucial by-product of the rice milling process, is one of these agricultural residues that could be used to make particleboards, and this waste accounts for 22% of rice production. Periwinkle shell, typical agricultural waste material in coastal areas, is now considered coarse aggregate incomplete or partial replacement for costly, unaffordable, or inaccessible crushed stones or local washed gravels, according to [3]. Engineered particleboards offered many advantages in achieving renewable materials and constructing green structures. Establishing the idea of using traditional agro-waste materials for particleboards in place of conventional ones for structural and non-structural purposes would demonstrate to designers and engineers that these locally manufactured composite products can fill in gaps where conventional ones are unavailable and perform as well as modern ones. Today's particleboard gives industrial users the consistent quality and design flexibility needed for fast, efficient production lines and quality consumer products. Particleboard panels are manufactured in various dimensions and with a wide range of physical properties that provide maximum design flexibility for specifiers and end-users [4].

2. MATERIALS AND METHODS

In this context, the objective of this paper is to investigate and carry out the comparative analysis of the physical and mechanical properties of locally-made composite particleboards with urea-formaldehyde adhesive made from Nigerian agro-waste materials, which are rice husk, periwinkle shell, sawdust, coconut shell, and snail shell to determine the viability and reliability for its usage in building construction. As shown in Table 1, moisture content and density were determined following [5] for the physical properties of the composite particleboard. While for the mechanical properties of the timber, such as static bending, compression strength parallel to the surface, and tensile strength parallels to the surface, were determined based on standards such as [6,5]. Response Surface Methodology was employed in the experimental design to achieve the mix ratio proportion between the aggregates. The response surface methodology (RSM) is one of the most widely used experimental designs for optimization because it allows for examining the effects of various factors and their interactions on one or more response variables. Raw data was entered into the software, which then ran and produced the best mix ratio result, as shown in table 3. The specimen material composition ratio is in runs from 1 to 10.

Table 1. List of tests to be carried out on the composite particleboards

S/n	Type of Test	Dimension
1	Moisture Content and Water Absorption	60mm x 20mm x 20mm
2	Density	60mm x 20mm x 20mm
3	Static Bending	300mm x 70mm x 20mm
4	Compression strength parallel to surface	70mm x 20mm x 20mm
5	Tensile strength parallel to surface	150mm x 20mm x 5mm

Table 2. List of Material Composition used for composite particleboards

S/n	Type	Material Composition	Run
1	A	Rice husk, periwinkle shell, coconut fibre and urea-formaldehyde adhesive	1 to 10
2	B	Sawn dust, snail shell, coconut fibre and urea-formaldehyde adhesive	1 to 10

Table 3. List of quantities of the aggregates used for each run specimens

Run	Rice Husk/ Saw Dust (%)	Rice Husk/ Saw Dust (1000g)	Periwinkle Shell/ Snail Shell (%)	Periwinkle Shell/ Snail Shell (2000g)	Urea-formaldehyde Adhesive
1	60	600g	20	400g	800g
2	90	900g	30	600g	800g
3	60	600g	40	800g	800g
4	80	800g	40	800g	800g
5	70	700g	30	600g	800g
6	70	700g	50	1000g	800g
7	90	900g	40	800g	800g
8	80	800g	50	1000g	800g
9	80	800g	30	600g	800g
10	50	500g	50	100g	800g

2.1. Preparation of Test Specimens

The materials used for this research study are rice husk, periwinkle shell, sawdust, coconut shell, snail shell, and formaldehyde adhesive. They were gotten from different sources such as the markets, farms, and neighbourhoods. The materials were dried to reduce the moisture content pre-existing at room temperature before use. Air circulates those materials and is dried up gradually. After drying those materials, they passed through a batching stage in which each material was measured based on the mix design obtained from the Response Surface Methodology consecutively. Batching by weight was considered in using an electrical digital weighing scale. The mixing processing was done manually and ensured the aggregates were uniformly mixed. The next step was to form the aggregates once they had been well mixed. A wooden molder was placed on a clean surface in the molding environment to facilitate the simple removal of the boards after being set and dried for the requisite time. To avoid displacement, the moulder was firmly secured to the surface, and the already mixed components were poured within the moulder and properly dispersed to cover the whole volume of the mould. After that, the tamper device was used to smooth the surface and compact the aggregates uniformly before being installed and allowed to cure for a week at room temperature.

2.2 Moisture content

The moisture content was determined following [7]. The specimens were cut to size at the sawmill and brought back to the laboratory to obtain their respective moisture content by oven drying them. The samples of each specimen were first weighed, and their weights were recorded as Mwet. After each weight of the specimens, each sample is placed inside the drying oven. After at least 24 hours, the samples of each specimen are brought out and reweighed to obtain their respective weights as Mdry. Moisture content is then computed using the formula shown in table IV.

2.3 Density

The specimens used were the same as those for the moisture content test. The mass of each specimen was recorded from a simple scale balance. At the same time, the volume was calculated based on the direct measurement of the length, width, and thickness of the required specimen using a Vernier calliper. The density of each specimen was then calculated by substituting the expression shown in table IV.

2.4. Tensile strength parallel to the surface

The shape and size of the samples were prepared according to [7]. The test piece was positioned so the yearly ring direction was perpendicular to the larger cross-sectional size. The toothed plate grips designed to apply axial load apply the load at the

2.5. Compression parallel to the surface

Each run's specimens were sliced and manufactured into rectangular cross-sections measuring 300 mm x 70 mm x 20 mm in size. Compression perpendicular to grain strength must be determined. The force was delivered to both ends of the test piece at a rate of 0.635 mm/min, causing the loading plates of the universal testing machine (UTM) to approach each other. When a deformation on the specimen was noticed, the test was stopped. The modulus of rupture and stress do the calculations at the percentage limit.

2.6. Static Bending

Three-point loadings were used to perform the static bending test following [6]. The sample was weighed and measured. The centre loading point and supports were indicated, and the test species were oriented perpendicular to the loading direction. After stabilizing the test parts with an initial load, the dial gauge was installed and set to zero to measure the deflection. The test piece was supported at the ends but not restricted, allowing for bending action throughout the member and ensuring flexure failure. The machine's speed was set to load the test item and allow for proper dial gauge monitoring. Before the failure, readings on the dial gauge were taken at intervals within the elastic limit. Where; $\boldsymbol{P}$ is the maximum load in Newton, $\boldsymbol{P_1}$ is the load at the proportional limit in Newton, $\boldsymbol{L}$ is the length of the span in millimetres, $\boldsymbol{b}$ is the width of specimen in millimetre, $\boldsymbol{d}$ is the thickness of specimen in millimetre, $\boldsymbol{y_1}$ is centre deflection at proportion limit load in millimetre.

Table 4. List of formulae used for the experiment

Test	Formulae	No
Moisture content (%)	$= \frac{Original\ weight - Oven\ dry\ weight}{Oven\ dry\ weight} x\ 100 = \frac{Mwet. - Mdry}{Mdry} x\ 100$	1
Density $(\frac{kg}{m^3})$	$= \frac{Mass}{Volume}$	2
Modulus of Rupture $(\frac{N}{mm^2})$	$M_{R=}\frac{3PL}{2bd^2}$	3
Modulus of Elasticity $(\frac{N}{mm^2})$	$M_{E=}\frac{3P_1L^3}{4bd^3y_1}$	4
Tensile strength $(\frac{N}{mm^2})$	$= \frac{Maximum\ Load\ (N)}{Smallest\ Cross\ Sectional\ Area\ (mm^2)}$	5
Compressive strength $(\frac{N}{mm^2})$	$= \frac{Failure\ Load\ (N)}{Cross\ Sectional\ Area\ (mm^2)}$	6
Stress at proportional limit $(\frac{N}{mm^2})$	$S_{pl=}\frac{3P_1L}{2bd^2}$	7

3. RESULT

Table 5. Composite particleboards moisture content test result

Type	Run	Low value	Run	High value	Mean
A	9	5.29%	6	9.50%	6.82%
B	9	0.97%	8	3.56%	1.85%

Table 6. Composite particleboards density test result

Type	Run	Low value	Run	High value	Mean
A	1	363.45 kg/m^3	4	482.65 kg/m^3	363.45 kg/m^3
B	9	384.19 kg/m^3	4	525.67 kg/m^3	491.85 kg/m^3

4. DISCUSSION

The above results are shown from each test type (A and B). From table 4, the moisture content value varied between 0.97% (Run 9, type B) and 9.50% (Run 6, type A). According to [8], the specimen having a high moisture value occurs due to poor water retention during the faster rate drying process. This may also be due to inappropriate compaction due to pores in the rice husk compact. When the presence of pores in the particleboard material is high, the material tends to lose moisture at a faster rate. According to [9], the physical properties are greatly influenced by low moisture content variation, enabling greater particleboards' reliability. The mass of the boards varied significantly from each other due to the variations in their composition. From table 5, the density test showed that the density of the composite material exhibited a range between 363.45 kg/m^3 (Run 1, type A) and 525.67 kg/m^3,(Run 4, type B). The particleboards' densities fall below the required range (600 kg/m^3 to 850 kg/m^3) for medium particleboards as stipulated by the values [10] standard. From table 6, the tensile strength value varied between 0.054 N/mm^2 (Run 7, type B) and 0.074 N/mm^2 (Run 7, type A). The minimum requirement of tensile strength for general-purpose boards, according to [11], is 0.24 N/mm^2. From table 7, compressive strength value varied 0.676 N/mm^2 (Run 10, type A) and 0.715 N/mm^2 (Run 6, type B). According to Nigerian Standards Organization, the minimum acceptable compressive strength for sandcrete blocks in Nigeria is 2.5 N/mm^2

(NSO, 1975), which prevents the specimens from being used as internal partition wall materials in non-waterlogged locations. From table 8, the modulus of rupture value varied between 0.946 N/mm^2 (Run 3, type B) and 3.043 N/mm^2 (Run 10, type A). The modulus of elasticity value varied between 67.502 N/mm^2 (Run 6, type B) and 259.283 N/mm^2 (Run 4, type A), and the stress of proportional limit value varied between 0.379 N/mm^2 (Run 3, type B) and 2.807 N/mm^2 (Run 10, type A). The static bending requirement for general-purpose boards, according to [11], is 11.5 N/mm^2 .The modulus of elasticity for type 1 mat-formed particleboard, according to [12], falls between 150 N/mm^2 – 350 N/mm^2, meaning the particleboard could be classified as 1-M-1 grade. Innovative research is required to address our country's growing demand for particleboards. The study found that locally sourced agro-waste materials are trustworthy and efficient in producing particleboards. Their non-biodegradability allows them to serve as a viable solution to users' needs. The result above shows that implementing the manual method to produce composite locally particleboard isn't improving in meeting the standard codes but could still be used in some situations such as for partitioning, ceiling boards, and furniture materials. This composite material compares favourably with other commercially available ceiling board materials. This study has equally shown that waste materials can be recycled into other materials, which can still be useful to man, thereby protecting the environment from waste disposal challenges.

Table 7. Composite particleboards tensile strength test result

Type	Run	Low value	Run	High value	Mean
A	10	0.056 N/mm^2	7	0.074 N/mm^2	0.064 N/mm^2
B	7	0.054 N/mm^2	2	0.066 N/ mm^2	0.059N/ mm^2

Table 8. Composite particleboards compressive strength test result

Type	Run	Low value	Run	High value	Mean
A	10	0.676 N/mm^2	5	0.714 N/mm^2	0.701 N/mm^2
B	3	0.705 N/mm^2	6	0.715 N/mm^2	0.710 N/mm^2

Table 9. Composite particleboards static bending test result

Test	Type	Run	Low value	Run	High value	Mean
Static bending						
Modulus of rupture	**A**	6	2.423 N/mm^2	10	3.043 N/mm^2	2.824 N/mm^2
Modulus of elasticity	**A**	6	170.564 N/mm^2	4	259.283 N/mm^2	222.636 N/mm^2
Stress of proportiona l limit	**A**	1	1.616 N/mm^2	10	2.807 N/mm^2	1.981 N/mm^2
Modulus of rupture	**B**	3	0.946 N/mm^2	2	1.553 N/mm^2	1.223 N/mm^2
Modulus of elasticity	**B**	6	67.502 N/mm^2	2	116.692 N/mm^2	94.768 N/mm^2
Stress of proportiona l limit	**B**	3	0.379 N/mm^2	10	0.728 N/mm^2	0.521 N/mm^2

Fig. 1. Tensile strength test procedures using Universal Testing Machine

Fig. 2. Static bending strength test procedures using Universal Testing Machine

Fig. 3. Compression strength test procedures using Universal Testing Machine

5. CONCLUSION

Nigeria's particleboard market is expanding steadily, and the end consumers are reached via importing the product.

While there are plentiful and untapped indigenous agricultural waste resources in Nigeria that could be used for non-loading construction materials. This study has demonstrated that Nigeria can rank among the top domestic manufacturers of particleboard. Numerous industries, including agriculture, construction, and the economy, stand to gain significantly from this study. Composite particleboards from major materials, rice husk, and sawdust with other constituents can be manufactured using a manual method to improvise when mechanical means are unavailable. The physical and mechanical properties of the board were quite good and gave positive results. The study's findings demonstrate that Type A specimens produce more realistic outcomes than Type B ones. In contrast, since only a few aspects of the board were considered for this work, additional research still must be done in this study area. It is essential to undertake further research on various agro-waste materials to enhance the usage of locally produced particleboard as a building material in Nigeria and reduce the country's total dependency on imported particleboards. Additionally, this will advance the science and technology used in such production. Recommendations to be considered are listed below;

1. The availability of improved and specialized equipment should be assessed to reduce the risk of inaccurate results obtained during the experiment. Also, mechanical means of production are highly required to enhance the test values in meeting the standard codes of particleboards.
2. Urea-formaldehyde adhesive possesses some shortcomings to the research, such as; loss of the glue bond due to time and under thermal, non-resistant to water or moisture content, etc., which has to be substituted or supported with other structural adhesives.
3. Particleboard exposed to moisture should be treated with paint or waterproofing material to prevent gradual and further damage.

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