LAUTECH Journal of Engineering and Technology 19 (1) 2025: 119-127
10.36108/laujet/5202.91.0111

Utilization of Local Gum Arabic as an Adhesive for the Production of Particle Board from Maize Cobs and Coconut Shells

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Article Info

Article history:

Received: Jan. 10, 2025
Revised: Feb. 02, 2025
Accepted: Feb. 12, 2025

Keywords:

Agricultural Waste,
Binder,
Characterization,
Formulation,
Furniture.

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ABSTRACT

The increase in cost of building and furniture materials like particle board, ceiling and roofing sheets in Nigeria increased by the day. Particle board is one of the primary products used in the manufacture of wood products such as furniture, cabinets, tabletops, kitchen worktops, pool tables and so on. Hence, the need to develop an alternative like the use of agricultural wastes to produce particle boards. In this study, maize cob, coconut shell and gum Arabic as adhesive were used in the development of particle board. The particle board was produced by mixing maize cob and coconut shell in different proportions. The physical and mechanical properties of the particle board such as density, water absorption, impact strength, compressive and tensile tests were investigated. The density ranged from 518.6 - 843.3 kg/m^3, water absorption was between 11.05 and 70.2% by varying time of immersion at 30min, 1hr and 2hr. The compressive strength, tensile strength and impact strength fell within the range of 15.9 - 20.15MPa, 18 - 62KPa and 175 - 274.06KJ/m^2 respectively. The results showed that the maize cob, coconut shell and gum Arabic are good materials for building and furniture applications.

INTRODUCTION

The establishment and advancement of novel construction materials derived from both degradable and non-degradable waste have the potential to bring about a significant transformation in the construction and waste management sectors. If these wastes are burnt directly, it results in very poor thermal efficiency and may create a lot of air pollution and contribute to global warming (Jabile *et al.*, 2022). The utilization of wood waste in particle board gives more advantages due to it not directly result in carbon emissions (Prasetiyo *et al.*, 2020). An environmentally friendly alternative for agricultural waste is using them for the manufacture of particulate composites, or particleboards. These particleboards are usually produced from wood particles bound together with synthetic adhesives or other binders, which are pressed under heat until the curing of adhesives is achieved (Abdulkareem *et al.*, 2017).

Particle board, also known as chipboard or low-density fiberboard, is a composite product manufactured from wood chips and a synthetic resin or other suitable binder under exposure to a hot press at a certain pressure and temperature. It has become one of the most popular wood-based composite materials for decorating materials due to its good thermal insulation, sound absorption, low density, and incredible machining properties.

Particle board is a product used mainly in the construction and furniture sectors (Jabile *et al.*, 2022). It is one of the primary products used in the manufacture of value-added wood products such as furniture, cabinets, millwork, stair treads, home construction, paneling, shelving, vanities, tabletops, sliding doors, interior signs, lock blocks, kitchen worktops, pool tables, educational establishments, floor underlayment and other industrial product applications (Nemli *et al*., 2009).

Generally, particle boards manufactured from wood particles are bonded with synthetic adhesives, such as urea-formaldehyde (UF) or phenol-formaldehyde (PF). These binders bring some environmental problems because they release formaldehyde emissions, which can be toxic to human health and the environment (Prasetiyo *et al*., 2020). These resins are derived from non-renewable petrochemical materials while carcinogenic formaldehyde is released during the particleboard production and application. Health hazards such as allergic, non-allergic, and mucosal respiratory symptoms, as well as cancer, are associated with these conventional binders resulting in an increasing global accumulation of hazards generated from particleboard manufactured using formaldehyde-based adhesives. (Barbu *et al*., 2017).

This is one of the reasons particle board manufacturers are looking for more environmentally friendly adhesives. A lot of bio-source compounds have been envisaged to replace the currently used synthetic adhesives. Various natural molecules have been studied for their adhesive properties on plant particles, such as lignin, lignosulfonates, proteins, polysaccharides, and citric acid.

Gum Arabic, a natural gum derived from the sap of Acacia trees, has gained attention for its potential as an adhesive in various industries. It possesses unique properties such as water solubility, film-forming ability, and adhesion strength.

Crop residues need to be recycled somehow, and directing such waste material to the production of particleboard panels is a possible alternative, given that as a rule particleboard panels can be produced from any lignocellulosic material capable of providing them with high mechanical strength and a pre-established specific weight (Rowell *et al*., 2000).

The increase in corn production is also followed by the increase in its solid waste, such as corn cob, so it will take an effort to handle this waste. Corn cob has become agricultural waste generated and has not been used optimally. Agricultural waste such as corn cob and coconut shell is excessively available in Nigeria, especially in the Southern Part of the country. One of the most successful approaches to the management of agricultural waste is the production of particle boards from it.

Owodunni *et al*. (2020) studied the combination of sweet sorghum bagasse (*Sorghum bicolor L. Moench*) and citric acid as the adhesive was employed in the production of particleboard, and the impact of pre-drying treatment and the citric acid content on the physical properties of the resulting boards was examined and analyzed. The pre-drying treatment on the sprayed particles and the high content of citric acid improved water resistance, and the mechanical properties of the particleboards met the requirement of particleboard of Type 18 of JIS A 5908 standard which concluded that sorghum bagasse has a good potential for raw material in producing particleboard.

Abdulkareem1 *et al*. (2017) studied the development of particleboards from sawdust and plastic-based resin (PBR) synthesized from waste Styrofoam as binder exhibited properties that were in tandem with the requirements of the American National Standard Institute (ANSI) A208.1 requirements. This standard specifies the required dimensions as well as the physical and mechanical properties for different grades of particleboards. The study observed that the sawdust-PBR particleboards exhibited better water penetration resistance, dimensional stability, mechanical properties and resistance to deformation when compared with urea-formaldehyde (UF) particleboards.

Erakhrumen *et al.* (2008) studied the mixtures of pine (Pinus Caribea M.), sawdust and coconut husk or coir using cement as a binder, parameters such as water resistance, strength properties and density of the particle board were enhanced with high cement content but were subsequently lowered with increased inclusion of coir in the mixture.

The demand for good quality building materials to replace traditional materials and the need for cost-effective and durable materials for low-cost housing has necessitated researchers to develop a variety of new and innovative building materials (CIRAD, 2010). Given this, there is a need to develop particleboard with the use of alternative raw materials such as maize cob and coconut shell using Gum Arabic as adhesive. This study therefore aims to develop particleboards with the use of alternative raw materials such as maize cobs and coconut shells using Gum Arabic as adhesive as well as examine the effect of the mixing ratios on the physical and mechanical properties of the particle boards produced.

MATERIALS AND METHODS

Sample Collection and Preparation

The maize cobs and coconut shells were collected from Itam market in Uyo, South-South Nigeria. The Gum Arabic was collected from the Chemical Engineering laboratory at, the University of Uyo. The maize cobs were washed, cut into smaller sizes, sundried for 24 hr to reduce the moisture content and then oven dried for 3 hours at 105ºC before being crushed. The maize cob was pulverized and sieved with the aid of sieve shakers to obtain particles passing through a British standard sieve of aperture size 2.0mm and 1.0mm mesh. The coconut shell was oven-dried for 3 hours at 105ºC and was crushed into smaller sizes and sieved using a U.S. standard mesh size of 4.75mm. Congealed Gum Arabic was broken up and ground into fine particles before diluting with water to form a liquid resin adhesive in a gum/ water ratio of 4:1 by weight. The water evaporated during heat treatment (Ndububa, 2013).

2.2 Formulation of Particle Board

The formulations of the particle board indicating the composition of the batches are presented in Table 1. Sample A1 was made up of only coconut shells while sample A2 contained 100% maize cob. Other batches were formulated from the combination of coconut shell and maize cob at various proportions as shown in Table 1.

Table 1: Composition of the Samples of the Particle Board

Samples	A1	A2	B1	C1	C2	D1	D2
Coconut Shell (%)	100	0	50	60	40	75	25
Maize Cob (%)	0	100	50	40	60	25	75
Gum Arabic	27.6	23.16	15.3	15.3	15.3	16.5	16.2

Production of Particle Board

The maize cob, coconut shell and liquid resin were weighed using a weighing balance. Thereafter, liquid resin, maize cob and the coconut shell were blended manually with a stirring rod for 15 minutes. After a homogenous mixture was obtained, the mixture was then poured into an iron rectangular mould with dimensions of 100 x 100 x 25 mm and labeled for the various formulations. Before this casting operation, cellophane was also placed on the mixture in the mould before the cover was placed in position. Tamping was done to give a "formed mat" which was covered up with steel metal and placed in an oven. The temperature of the mixture was raised to 100°C over 20 minutes, enough to evaporate the water content and dry the samples before being cooled in a water bath for 5 minutes (Ndububa, 2013). The resulting board was then removed from the mould. The samples of particle boards produced using different formulations are presented in Figure 1.

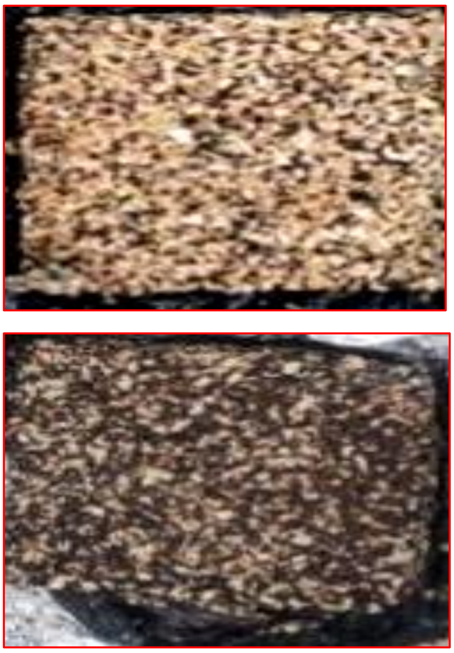

Figure 1: Sample of produced particleboard

Curing

Once the water content in the resin had evaporated, the boards were pressed with the AMBROS universal testing machine for 7 minutes, reducing the thickness of the particle board samples to an average of 12 mm. After pressing and following Ndububa, (2013), the particleboards were placed again in the oven and conditioned for 7 hours at a curing temperature of 30°C. The composite was wrapped in aluminum foil during this process. Afterward, the composite was sun-dried for an additional 7 days.

Characterization of Particle Board

The developed particle boards were characterized for density, water absorption capacity, tensile and compressive strengths

Density

The density of the products was evaluated to show what grade these particle boards can be classified. The density of each of the specimens was obtained by dividing the weight of each specimen (W_i) by its corresponding calculated volume (V_i). Their weights were obtained using an analytical- - weighing balance, while the volume was obtained by multiplying their respective measured length, width and thickness.

$$Density = \frac{W_i}{V_i} \quad (1)$$

Water Absorption Capacity

Each sample was oven-dried at 110°C to constant weight (W_1) before being immersed in water at room temperature for 30 minutes, 1 hour and 2 hours. The samples were removed from the distilled water, cleansed with a cotton fabric and weighed (W_2). The amount of water absorbed (W) by each sample was calculated using:

$$W = \frac{W_1 - W_2}{W_1} \times 100 \quad (2)$$

Impact strength

The test was conducted using a pendulum impact testing machine JBS-300N model and determined using the ASTM standard testing method. A standard sample measurement was done with dimensions 2× 7 cm while ensuring the original thickness was maintained, then it was placed on the plate of the impact testing machine, wherein the handle jack was carefully released for the load to strike the particle board sample. Then, the energy of the impact was recorded and the impact strength was calculated by:

$$Impact\ Strength = \frac{A_E}{A} \quad (3)$$

Where: A_E = Absorbed Energy

A = Cross-sectional area of a test piece

Compressive strength

The compressive strength test was carried out using the AMBROS universal testing machine based on the ASTM C864/05 standard. The specimens were prepared according to this standard with dimensions 20 by 20mm and were tested on a support span of 130mm as the standard method. The load at which each sample was compressed because of the force applied to it by the machine was recorded. However, the compressive strength was calculated using.

$$CS = \frac{P_{max}}{A} \quad (4)$$

$$A = s \times B \quad (5)$$

Where: CS= Compressive strength

P_{max} = Maximum load in kg

A = Cross-sectional area of test piece

s = Thickness

B = Breadth

Tensile strength

This test was conducted using the Universal Testing Machine (UTM) at the University of Uyo, Mechanical Engineering Laboratory under the supervision of the Laboratory Engineer and Technician. The samples were prepared for this test according to the ASTM D309 Standard while keeping the thickness of the particle board. After which the sample was carefully placed in the tensile testing machine and clamped at both ends. The Machine was turned on and the load under which each sample fractured was recorded. The Tensile strength was calculated by:

$$TS = \frac{P_{max}}{A} \quad (6)$$

$$A = s \times B \quad (7)$$

Where: TS= Tensile strength

P_{max} = Maximum load in kg

A = Cross-sectional area of test piece

s = Thickness

B = Breadth

The speed of the tensile testing machine was set to 5 mm/min and a gauge length of 40mm was used. The specimen dimension was 10mm thick with a width of 16mm (ASTM, 2021).

RESULTS AND DISCUSSION

Physical properties of particle board

The physical properties of the particle board are presented in Table 2. Water absorption is the ability of a material to absorb water or moisture. The water absorption values of the formulated board obtained ranged between 11.05 and 37.3 % for a water absorption time of 30 min, 17.2% - 43.7% when the absorption time is 1hr and 20.06 - 70.2% for an absorption time of 2hrs. The highest water absorption was obtained in sample A2 with a composition of 100% maize cob and 0% coconut shell. The values were 37.3%, 43.7% and 70.2% for water absorption time of 30 min, 1 hr and 2 hrs, respectively. The result shows that maize cob increased water absorption of the boards and this is due to the hygroscopic nature of the lignocellulose content of the maize cobs which allows for moisture intake (Giana *et al*., 2018). The specification for the average water absorption capacity of a standard particle board is 0.66% soaked for a minimum of 2 minutes and 3.96% soaked for a maximum of 12 minutes (Ndububa, 2013). The high water absorption capacity of the particle board developed does not meet this requirement.

Table 2: Physical Properties of Samples of the Particle Board

Sample	Density (kg/m^3)	Water Absorption (%)		
		30 min	1 hr	2 hr
A1	821.30	11.05	17.20	20.06
A2	518.60	37.30	43.70	70.20
B1	744.00	29.20	31.80	38.80
C1	777.00	25.70	27.50	31.60
C2	718.00	31.30	35.30	51.80
D1	843.30	18.44	28.32	33.00
D2	662.00	36.70	39.63	68.77

The density of the board ranged from 518.6 kg/m^3 to 843.3 kg/m^3 as depicted in Table 2. The highest density was 843.3 kg/m, it was obtained for sample D1 with 75% coconut shell and 25% maize cob. Since the maximum density obtained is less than 850 kg/m^3, then the manufactured boards can be graded according to ANSI A208.1(1999) as medium-density particle boards, Grade2 (MD-2).

Mechanical properties of particle board

The mechanical properties of the various samples are shown in Table 3. The compressive strength of the formulated boards ranged between 15.9 -20.15 MPa. It is observed that boards C1 and A1 had the highest and lowest compressive strength of 20.15MPa and 15.90MPa respectively. This implies that the impact strength of sample C1 to compressive loading will be greater than that of sample A1. The minimum acceptable compressive strength for sandcrete blocks in Nigeria according to Nigerian Standard is 2.5MPa (Ndububa, 2013). This shows that developed particle boards showed better compressive strength and can be used as a wall material for internal partitioning.

Table 3: Mechanical Properties of Formulated Particle Board

Sample	Mechanical Properties		
	Compressive Strength (MPa)	Tensile Strength (KPa)	Impact Strength (KJ/m^2)
A1	15.9	18	227.46
A2	16.5	22	175.00
B1	19.10	54	258.34
C1	20.15	58	262.14
C2	17.28	62	252.86
D1	18.06	43.5	274.06
D2	17.02	47	202.50

The tensile strength of a material is a measure of the force required to pull a material to the point where it breaks (Zoback, 2007). Their resistance to tensile force was between the ranges of 18KPa -62 KPa as shown in Table 3. Sample C2 performed better in resistance to tensile force compared to sample A1 which had performed the least. The percentage of coconut shells and maize cob in the mix ratio contributed a lot to the samples' tensile strength. The minimum requirement of tensile strength for general-purpose boards according to standards is 240KPa (Ndububa, 2013). The developed particle board had lower strength than the requirements for general purpose board. So, it will not be able to bear more transverse load than the conventional particle board.

Impact strength is the resistance of a material to fracture by a blow expressed in terms of the amount of energy absorbed before fracture. This implies that the ability of each board to absorb energy when fractured at high velocity decreases. The toughness of the formulated boards as shown in Table 3 indicates their impact strength was found between 175 and 274.06 KJ/m^2. Board D1 exhibited the highest impact strength while A2 showed the lowest. The impact energy increased with increased coconut shell content as seen in boards B1, C1, C2 and D1 where the coconut shell content was greater than 30% as well as the presence of maize cob. Board A2 had the lowest resistance to impact energy, which had no coconut shell content.

Comparison of the physical and mechanical properties of particle board with different wastes

From Table 4, it is observed that the properties vary with the materials used. This conforms with Onuorah, (2011) who stated that particle board properties are determined by manufacturing parameters, but unfortunately, each parameter while enhancing certain properties may also have adverse effects on other properties.

Table 4: Physical and mechanical properties of particle board with different wastes

S/N	Raw Materials	Resin used	Properties					References
			D (kg/m^3)	WA (%)	TS (MPa)	CS (MPa)	IS (KJ/m^2)	
1	Afzelia Africana wood residues	Chemical additives ($CaCl_2$,$MgCl_2$ and $AlCl_3$)	-	8.52-44.07	0.19-0.59	-	-	Sotannde, 2012
2	Jatropha carcus	No binder	-	7.5-9.5	-	-	-	Hidayat *et al.*, 2014
3	Saw dust and wood shavings	Gum Arabic	692-864	-	0.32-2.28	1.74-9.02	-	Ndububa, 2013
4	Pine sawdust and coconut husk	Portland Cement	1040-1790	23.4-61.8	-	-	-	Erakhrumen *et al.*, 2008
5	*Gmelinaarborea*u	Modified Cassava starch	270-330	137-174	0.19-0.20	-	-	Ayinde *et al.*, 2020
6	Coconut shells and maize cobs	Gum Arabic	518.6-843.3	11.05-70.2	0.018-0.062	15.9-20.15	175-274.06	Present Study

D- Density, WA- Water Absorption, TS- Tensile Strength, CS- Compressive Strength, IS- Impact Strength

CONCLUSION

The development of particle board from maize cob and coconut shell using local gum Arabic as the adhesive was successful. The results obtained from the characterization of the formulated particle board are satisfactory, however, batches C1, C2 and D1 satisfied all the properties tested for and hence considered the best proportion of maize cob to coconut shell for particle board production. It can be concluded that a blend greater than 40% coconut shell and 25% maize cob improved the physical and mechanical properties. This can proffer a solution to the challenge of agricultural waste disposal to produce products like particle boards which can be used as an excellent replacement for wood-wood-based composite materials.

ACKNOWLEDGEMENT

The authors thank the University of Uyo, Uyo for the use of the laboratory of the Department of Chemical and Civil Engineering, Faculty of Engineering.

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