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Mechanical Properties of Particleboard Made from Mahogany Leaves Using Gum Arabic as Binder

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ABSTRACT

This paper presents the findings of an investigation into the use of mahogany leaves particles for the production of gum Arabic bonded particleboards. Fresh mahogany leaves, air-dried to a target moisture content of 10% were crushed to an average particle size of 2mm. Mix ratios of 2:1, 2.5:1, 3:1, and 3.5:1 of gum Arabic to the crushed mahogany leaves by weight of the mahogany leaves were produced respectively. Twenty four (24) particleboards of sizes 200mm length, 50mm width, and 6mm thick were produced. The boards were cured for 28 days in an acclimatized room, after which tests on modulus of rupture (MOR) and modulus of elasticity (MOE) were carried out in accordance with ASTM D1037-93 procedures. Cost-effective analysis was also carried out to obtain comparison with conventional particleboards available in the market. Results of the investigation indicated that the modulus of rupture (MOR) and modulus of elasticity (MOE) with mean and standard deviation in parenthesis, are 22.235N/mm^2 (2.92827N/mm^2) and 16131.04N/mm^2 (4806.63N/mm^2) respectively, were above 3.0N/mm^2 and 550N/mm^2 as the minimum values specified by ANSI/A208.1-1999. The particleboards produced met the minimum standard for general purpose boards, and adjudged cost-effective and cheaper as compared to the conventional particleboards.

KEYWORDS: Cost-effective analysis, gum Arabic, mahogany leaves, mechanical properties, Particleboard.

1.0 INTRODUCTION

The growing shortage of wood has also led to the development of suitable alternative materials for construction, to which particleboard is one such material which is being considered as a potential substitute for wood and wood-based board products [1]. Wood and wood-based composite boards have been researched into and manufactured due to their reasonable cost in spite of the low weight to high strength ratio [2]. Particleboards are wood-based panel product that are conventionally produced using wood and wood wastes such as shavings, flakes, wafers, chips, sawdust, and strands [3]. Particleboard have found applications in areas like furniture, kitchen cabinets, flooring, wall bracing, ceiling boards, partitioning and cladding [4]. The materials used to bond the particles together are mostly synthetic resins but other additives can be added to improve some properties of the board [5].

Several types of resins such as polyimides, thermo-set epoxies, polyurethane resins, phenol-formaldehyde, isocyanate-based adhesives, epoxy resins, resorcinol formaldehyde, are commonly used, although urea-formaldehyde is the cheapest and easiest to use [5].

The increased demand for wood and wood-based panel products in Nigeria has placed significant pressure on current forest resources, which has resulted in over exploitation and unregulated harvesting of trees in both the natural and plantation forest leading to the recent interest in lesser-known timber species [4]. With all these efforts, timber supply is still nowhere close to meeting global demand for wood products resulting in continuous cutting without replacement [6]. [7] stated that this lack of balance between consumption and sustainable supply will have serious social, economic as well as environmental implication on the populace. This demand has led to the need to find alternative raw materials for the production of boards and panels. Trees are planted all around us and these trees shed leaves which reach its peak in the dry season. In most under developed and developing countries, Nigeria inclusive, these leaves have very limited reuse capacity after the target wood has been cut down and they are inappropriately discarded or openly burnt. This improper disposal of leaves has many negative environmental consequences. For instance, burning these leaves leads to an increased level of carbon dioxide in the atmosphere, which contributes to global warming. These wastes could also cause blockage of drains which consequently results in flooding. Accumulated wastes from leaves when allowed to decay release offensive odours, thereby contributing to air pollution, and also serve as a breeding ground for mosquitoes and flies which spread several diseases. The reuse of these leaves will offer potential benefits environmentally, socially and economically because they are cheap, abundantly available, resource-oriented when handled appropriately and the environmental problems associated with its disposal are eliminated [8].

Mahogany leaves are obtained from Mahogany (*Swietenia mahogani*), a tree of the Meliaceae family which can be found in Cameroon, Central African Republic, Chad, Cote d'Ivoire, Equatorial Guinea, Gambia, Ghana, Guinea, Guinea-Bissau, Mali, Niger, Nigeria, Senegal, Sierra Leone, Sudan, Togo, Uganda, Australia, Cuba, India, Indonesia, Puerto Rico, Singapore, South Africa, and Vietnam [9]. This tropical tree sheds leaves like temperate tree, with leaves falling in the spring towards the end of the dry season. When the useful parts of these trees have been used, for example, when used for decoration, the leaves (mahogany leaves) served as nothing but contribute to the wastes and littered the whole environment or dumped in the forest when the tree is being used for timber. [9] shows that oleoresin, which is used as gum or resin, exist in the vessels of the stem of mahogany species. This is an indication that when the leaves are dried, crushed, pressed and used to manufacture particleboard, it may account to the durability of the wood composite and resistance to insect and fungal attack which are some desirable properties in any Particleboard material. This research is therefore aimed at evaluating the mechanical properties of particleboards produced from mahogany leaves with gum Arabic as binder, and conducting cost analysis of the new material.

2.0 MATERIALS AND METHODS

2.1 Materials

2.1.2 Mahogany Leaves

Mahogany leaves were obtained from the Faculty of Agriculture model farm in Bayero University Kano, Kano State, Nigeria. The leaves were cleaned and air-dried to remove moisture after which the leaves were crushed to a maximum size of 2mm and sieved through the British Standard sieves with apertures of 0.8mm and 2mm as shown in Figure 1. The particles were further air-dried for 48 hours to reduce the moisture content to target moisture of 10%.

2.1.3 Gum Arabic

The gum-Arabic adhesive used was obtained from Kurmi market, Kano State, Nigeria (Figure 2). The raw gum-Arabic granules were cleaned and mixed thoroughly with water to form a homogeneous mixture of a gum-Arabic solution to a concentration of 1333.3g/dm^3.

Fig. 1: Milled Mahogany Leaves Particle Fig. 2: Gum Arabic Granules

2.2 Methods

2.2.1 Specific Gravity Test on Mahogany Leaves Particles and Gum Arabic

The specific gravity of any material is defined as the ratio of the weight of a given material to the weight of an equal volume of water. This test was conducted on Mahogany leaves particles and gum Arabic in accordance with [10]. The setup for determining specific gravity is shown in Figure 3.

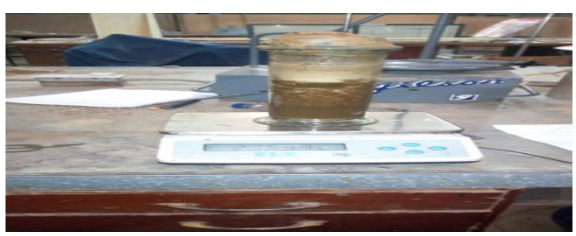

Fig. 3: Specific Gravity Test Setup for Mahogany Leaves Particles

2.2.2 Preparation and Production of Mahogany Leaves Particleboards

The milled and sieved mahogany leaves were transferred into hot water at a constant temperature of 85°C to extract likely inhibitory to binding compounds such as glucose, hemicelluloses and lignin from the leaves particles as suggested by [7]. The extracted particles were air-dried to attain approximately 10% moisture content before use. The milled leaves were mixed thoroughly with the gum-Arabic adhesive at the ratio described in Table 1 manually to obtain a uniform lump-free matrix as shown in Figure 4. After mixing, the material was placed in a steel mat-forming box, with dimensions (Figure 4) and manually pre-pressed. The box was then further pressed using 155kg load for 48 hours. The mat-forming box was covered with a polythene sheet prior to board formation to prevent the boards from sticking onto the box as shown in Figure 5.

Table 1: Mix Ratio for The Production of GA/ML Particleboard (By Weight of Mahogany Leaves)

TREATMENT, T (Gum-Arabic-Mahogany Leaves Ratio)	Adhesive Type	(%)	Material Type	(%)
T1(2:1)	Gum Arabic	66.7	Mahogany Leaves	33.3
T2(2.5:1)		71.4		28.6
T3(3:1)		75		25
T4(3.5:1)		77.8		22.2

Fig. 4: Homogeneous Mixture of Mahogany Leaves Particleboard Materials

Fig. 5: Protection of Freshly Prepared Particleboard using Poly Ethane

The boards produced were stabilized in an acclimatized room of temperature (20±2°C) and relative humidity of 65±2% for 28 days as shown in Figure 6 and 7. The above procedure was repeated for the varying ratio of mahogany leaves particles to the gum-Arabic solution presented in Table 1.

Fig. 6: Drying of Mahogany Leaves Particleboards

Fig. 7: Conditioning of the Mahogany Leaves Particleboards

2.2.3 Determination of Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)

Static bending tests were conducted on specimens after conditioned in an acclimatized room, (20±2°C) temperature and relative humidity of 65±2% for 28 days. Twenty four number (24) samples were produced and tested in accordance with [11]. The test was conducted using a universal testing machine assembly (beam deflection unit).

3.0 RESULTS AND DISCUSSIONS

3.1 Selected Elemental Composition of Mahogany Leaves Particles and Gum Arabic

The elemental composition test was conducted to know the dominant elements present in the mahogany leaves particles and gum Arabic adhesive used in order to know the likely behavior of the particleboards in various states of the application. The dominant elements present in mahogany leaves particles and gum Arabic as shown by the laboratory result presented in Table 2 are Calcium, Magnesium, and Zinc. The non-toxic nature of the elements present in the particleboard materials makes the gum Arabic-mahogany leaves particleboard to be environmentally friendly; especially when in contact with water since the reaction of such materials with water will not result in the formation of toxic compounds and as such may be used for wide application in packaging. This may also help to eliminate the health hazards resulting from high formaldehyde emission from urea-formaldehyde resin-based particleboards.

Table 2: Selected Elemental Composition of Mahogany Leaves Particles and Gum Arabic

Elements	Mahogany Leaves	Gum Arabic
	Concentrations in (mg/kg)	Concentrations in (mg/kg)
Cu	0.14	116.55
Ca	321.17	901.84
Mg	15.54	1333.6
Zn	1.58	26.51
Fe	0.98	192.12
Mn	0.07	20.22

3.2 Specific Gravity of Mahogany Leaves Particles and Gum Arabic

The specific gravity of mahogany leaves particles (MLP) and gum Arabic (GA) adhesive as shown in Table 3 are 0.81 and 1.93 respectively. The low density of the MLP is a desirable property of any particleboard material. The high specific gravity of GA adhesive in relation to that of the MLP used can explain the reason why the mix ratio of the materials in the production of the boards in Table 3; although showing high quantity for adhesive in the mix, in actual sense the quantity of mahogany leaves particles is higher in the mixes considered.

Table 3: Specific Gravity of Particleboard Materials

Sample	Specific Gravity
Mahogany leaves particles	0.81
Gum Arabic	1.93

3.3 Modulus of elasticity (MOE) and Modulus of rupture (MOR)

3.3.1 Effect of Material Variables on MOR and MOE of the Particleboards

The mean values of modulus of rupture of the different boards tested are presented in Figure 8. The highest value of modulus of rupture (25.94N/mm^2) was obtained for particleboards produced using an adhesive-mahogany leaves ratio of 3.5:1 while the lowest modulus of rupture (19.46N/mm^2) was obtained for particleboards produced using an adhesive-mahogany leaves ratio of 2:1. The relatively high values of modulus of rupture recorded could be as a result of the random distribution of the particles in the boards [7]. This finding indicates that the boards are mechanically stable and can resist deformation under load. The values of modulus of rupture were also found to be increasing with increase in gum Arabic content of the mix, which may be due to the availability of enough binder to coat the surfaces of the mahogany leaf particles, there-by displacing the air in the void spaces, and as such increasing the bond between individual particles, which in turn resulted in increase in the flexural strength of the overall board. The American National Standard Institute, [12] specify a minimum modulus of rupture of 3.00 N/mm^2 for general-purpose particleboards. The results obtained in this study show that all the boards produced using an adhesive-mahogany leaf ratio of 2:1, 2.5:1, 3:1 and 3.5:1 met the requirements specified by the American National Standard Institute for general-use particle boards [12]. In engineering, not only high strength and high-performance materials are needed but also cost-effective materials. Therefore, by adopting particleboards from the first treatment T1 which also satisfy the code requirement will help in producing particleboards at a cheaper cost since the quantity of the materials used is less compared to that of the subsequent treatments.

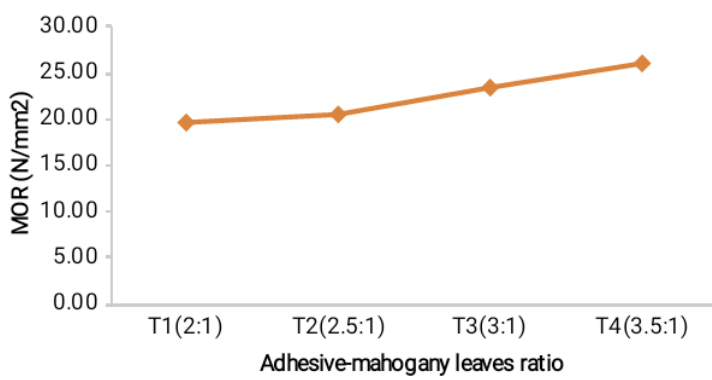

Fig. 8: Average Modulus of Rupture of Adhesive-Mahogany Leaf Particleboard using different adhesive-mahogany leaf ratio

Figure 9 shows the values of modulus of elasticity of the particleboards. The values ranged from 12,537.05N/mm^2 to 23,149.12N/mm^2. The highest modulus of elasticity was obtained for particleboards with an adhesive-mahogany leaves ratio of 3:1 while the lowest modulus of elasticity was obtained for particleboards with an adhesive-mahogany leaves ratio of 2:1. The values of modulus of elasticity were also found to be increasing with increase in gum Arabic content of the mix which may be due to the availability of enough binder to coat the surfaces of the mahogany leaves particles, there-by displacing the air in the void spaces, and as such increasing the bond between individual particles, which in turn resulted in increase in the flexural modulus of the overall board. The results presented are also in agreement with those reported by [13]. The minimum acceptable value of modulus of elasticity as specified by the American National Standard Institute standard [12] is 550N/mm^2. The results obtained show that all the boards produced met this minimum requirement of the American National Standard Institute for general-use particleboards.

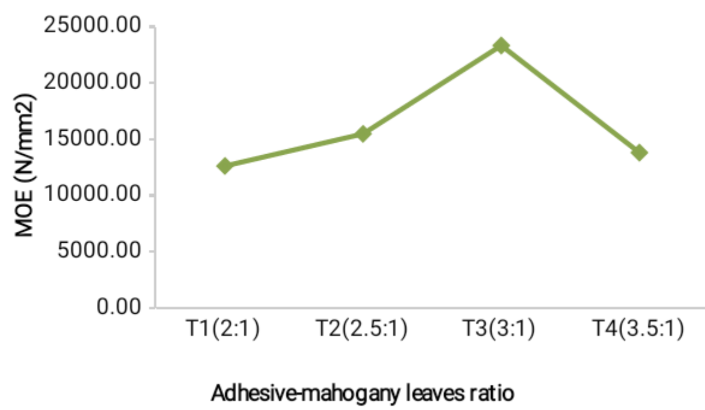

Fig. 9: Average Modulus of Elasticity of Adhesive-Mahogany Leaf Particleboard using different adhesive-mahogany leaf ratio

3.3.2 Effects of Density on the Modulus of Rupture of Mahogany Leaves Particleboard

Practically all the physical and mechanical properties of particleboards are related to density. Figure 10 shows the relationship between particleboard density and its modulus of rupture. From this graph, it can be observed that for each mix ratio, modulus of rupture increases with increase in density of the board. This is as expected because the more the particles are compacted, the greater the contact between them, thereby achieving good chip-to-chip contact and consequently increasing the density and strength of the board. However, in engineering, lightweight but high strength materials produced at a relatively cheap cost are preferred. Since particleboards from the first treatment T1 satisfies the requirements of the code and reduces the number of materials used, it can be adopted for use.

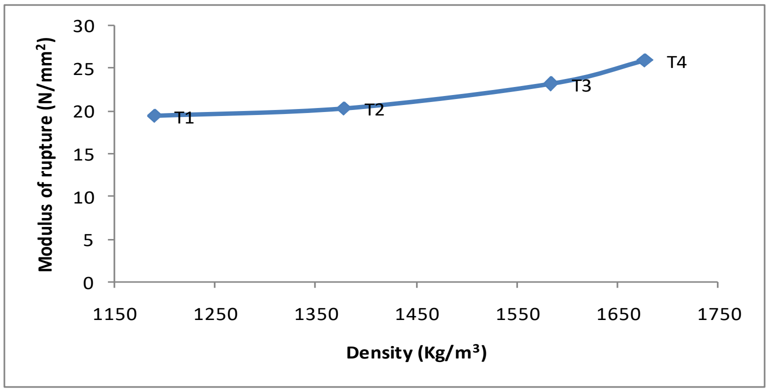

Fig. 10: Modulus of Rupture against Density

3.3.3 Effect of Density on the Modulus of Elasticity of the Particleboards

Figure 11 shows the relationship between modulus of elasticity and density of the mahogany leaves' particleboards. Modulus of elasticity increases with increase in density from 12537.05N/mm^2 at 1188.89Kg/m^3 to 23149.12N/mm^2 at 1583.33Kg/m^3 for the first three mixes but decreases afterward to 13619.40N/mm^2 at 1677.78Kg/m^3. The sudden decrease may be as a result of too much quantity of binder that has made the particleboard too brittle.

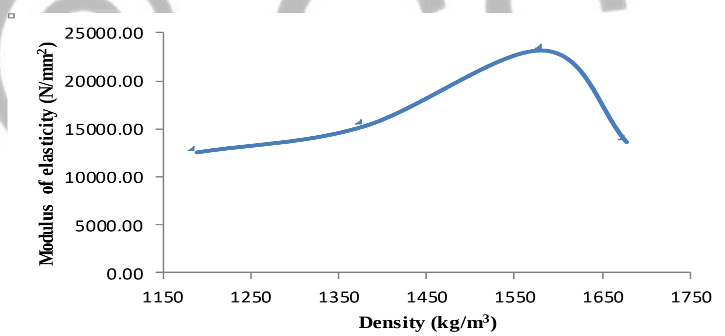

Fig. 11: Modulus of Elasticity against Density

3.4 Cost Analysis of Producing Mahogany Leaves Particleboard

Table 5 shows the cost analysis to produce mahogany leaves particleboard. ₦3,300 was used to produce each square meter of the mahogany leaves particleboard which is less compared to the ₦5,500 per square meter of the conventional urea-formaldehyde particleboard (Brazilian Brand) and ₦5,000 (Indian Brand), sold at the market. This shows that mahogany leaves particleboard is more economical.

Table 5: Cost of Materials and Utilities

	Cost of Materials and Utilities	
Materials	Quantity	Cost (N)
Gum Arabic	0.0045 ton	750
Mahogany leaves		0
Drying and Milling		300
Polyethene		20
Water	5 Liters	20
Labour		1800
Total		2,890

L(m)	B(m)	D(m)
0.2	0.05	0.006

Area (m^2) of 1 sample	0.01
Number of Board Samples	88
Total area	0.88
Cost per square meter	₦3,284.091

$$\text{Cost ratio} = \frac{3284.091}{5500} = 0.59$$

4.0 CONCLUSIONS

In this paper, the mechanical properties of particleboards produced from mahogany leaves particles and gum Arabic as binder were investigated and the following conclusions can be drawn:

1. Dominant elemental composition present in Mahogany Leaves particles and gum Arabic are; Cu(0.14mg/kg : 116.55mg/kg), Ca(321.17mg/kg : 901.84mg/kg), mg(15.54mg/kg : 1333.60mg/kg), Zn(1.58mg/kg : 26.51mg/kg), Fe(0.98mg/kg : 192.12mg/kg) and Mn(0.07mg/kg : 20.22mg/kg) respectively.

2. Particleboards produced by the weight of gum-Arabic to mahogany leaves particles of 3:1 satisfy the ANSI/A208.1-1999 standard on the mechanical properties of general-purpose boards.

3. Particleboards produced using gum-Arabic to mahogany leaves ratio of 3.5:1 have higher flexural strength while that of ratio 3:1 have higher MOE with average values of 25.94N/mm^2 and 23,149.12N/mm^2, respectively. The particleboards produced can be classified as high-density boards (H) for having all density values above 800kg/m^3.

4. An environmentally friendly particleboard that satisfies ANSI/A208.1-1999 standards can be produced using mahogany leaves particles and gum Arabic as binder.

5. Cost-effective particleboard can be produced from mahogany leaves due to the low-cost ratio of 0.6 obtained.

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