American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-8, pp-314-325
www.ajer.org
Research Paper Open Access

Suitability of Mango Seed Shell Particles and Recycled High Density Polyethylene (RHDPE) Composites for Production of Particleboard

Adewuyi Micheal Abolaji[1], Oyinlola Kofoworola Adeyinka[1], Akindapo Jacob Olaitan[1]

[1]Department of Mechanical Engineering, Nigerian Defence Academy, Kaduna-Nigeria.
Corresponding Authors: Adewuyi Micheal Abolaji

Abstract: *Suitability of using mango shell particles as alternatives to wood-based particleboard composite manufacturing has been investigated in this study. The mango shell composite boards were produced by compressive moulding using recycled high density polyethylene (RHDPE) as binder. The RHDPE was varied from 30 to 70 wt. % at intervals of 10 wt. % using 420μm particle size. The microstructure, water absorption (WA), thickness swelling index (TS), modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding strength (IB), impact strength, and hardness values of the boards were evaluated. From the results, boards produced using 60 % RHDPE gave the best physical and mechanical properties as follows: modulus of rupture 11.49MPa, MOE of 2450MPa, IB of 0.58MPa, and hardness value of 5.17HBR. The uniform distribution of the agro-waste particles and the RHDPE in the microstructure of the composites is the major factor responsible for the improvement in the mechanical properties. Equally, the MOE, MOR and IB meet the minimum requirements of the European standards (BS EN 312:2003) for general purpose boards for paneling, ceiling and partitioning. Hence mango shell particles can be used as a substitute to wood-based particleboards for general purpose applications with a minimum cost of production.*

Keywords: *compressive moulding, mango shell particles, microstructure, particle board composite, thickness swelling index, water absorption.*

Date of Submission: 11-08-2017 Date of acceptance: 31-08-2017

I. INTRODUCTION

The demand for wood in the forest industry has been increasing but the production of industrial wood from the natural forests continues to decline. While decline in forest resources in developing countries is due to depletion of the resources withdrawal of forest areas from industrial production for other uses such as recreational areas also contributes to this resource depletion problem. In addition, there is a significant pressure on standing forest resources as a result of higher demand for wood in the forest industry due to the increasing population and new areas of application. Consequently, there is the need to source for an alternatives to wood as the raw material **[1].**

The demand for wood composites from waste wood has been increasing as timber resources in natural forests decline. The use of renewable biomass as a raw material in composites production has been undertaken as an alternative source that may result in several benefits such as environmental and socioeconomic situations **[2].** Being a potential source of the end uses of wood-wastes and their possible reuse products, particleboard has found typical applications as in flooring, wall and ceiling panels, office dividers, bulletin boards, furniture, cabinets, counter tops, and desk tops **[3].** The production of particleboard from recycled wood-based wastes provides the most reasonable way to reuse such waste materials **[2].**

Wood composite industries demand more wood raw material everyday despite the fact that the forest resources are diminishing. The decline in wood material source has led researchers to study non-wood ligno-cellulosic biomass utilization in composite manufacturing including particleboard **[4].** Agricultural waste materials and annual plant fiber have become alternative raw materials for the production of particle or fiber composite materials **[4].** The most frequently preferred alternative to non-wood materials are flax, bagasse, hemp, reed, and cereal straws such as rice and wheat straw **[2]**. Today chemical pulp and panel products using wheat straw and other crop residues are being commercially manufactured in a number of countries including Nigeria **[5].** There is still a growing need to find alternative sources of raw materials for composite manufacturing.

The use of agricultural residues as raw materials in the forest industry is not new as it dates back to 1900s for pulp and panel industry. The observed problems with industrial usage of agricultural residues in the forest industry are the high cost of collection, transportation, and storage. Some of these problems could be overcome by building local, small scale mills close to the rural areas **[6].**

II. REVIEW OF EXISTING LITERATURES

Orsar **[50]** investigated the suitability of using banana and orange peels as alternatives to wood-based particleboard composites. The banana and orange peels composite boards were produced by compressive moulding using recycled low density polyethylene (RLDPE) as binder. The RLDPE was varied from 30 to 70 wt. % at interval of 10 wt. %. For each agro wastes, two different boards were developed from 420µm and 710µm particle sizes. The microstructure, water absorption (WA), thickness swelling index (TS), modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding strength (IB), impact strength, and hardness values of the boards were determined. From the results, the researchers observed that boards produced using 710µm size particles at 60 wt. % RLDPE gave best physico-mechanical properties as follows: modulus of rupture of 11.65 MPa, MOE of 2400 MPa, IB of 0.60 MPa, and hardness value of 5.17 HBR. The uniform distribution of the agro-waste particles and the RLDPE in the microstructure of the composites was the major factor responsible for the improvement in the mechanical properties. Equally, the MOE, MOR and IB meet the minimum requirements of the European standards **[5]** for general purpose boards for paneling, ceiling and partitioning. Hence, banana and orange peels particles can be used as a substitute to wood-based particleboard for general purpose applications.

Lee *et al* **[42]** carried research into the potential uses of rice husk and attempted to determine the optimum pre-treatment conditions used for the manufacture of rice husk board. Their conclusion was that the steam explosion method gave the best result. The advantage of rice husk flour wood particleboard are the built-in insulation properties and low cost.

Recently Idris *et al* **[43]** studied eco-friendly watermelon peels as alternatives to wood-based particleboard composites. The watermelon peel composite boards were produced by compressive moulding using recycled low density polyethylene (RLDPE) as binder. The RLDPE was varied from 30 to 70 wt. % at interval of 10 wt. %. The microstructure, water absorption (WA), thickness swelling index (TS), modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding strength (IB) and impact strength properties of boards were determined. The results showed that high modulus of rupture of 11.45N/mm^2, MOE of 1678 N/mm^2, IB of 0.58 N/mm^2 were obtained from board produced at 60 wt. % RLDPE. They concluded that the MOE, MOR and IB meet the minimum requirements of European standards, for general purpose applications such as paneling, ceiling and partitioning.

Aigbodion *et al* **[44]** investigated the kinetics of isothermal degradation studies by thermogravimetric data: effect of orange peels ash on thermal properties of high density polyethylene (DTA/TGA). The high density polyethylene (HDPE) composite reinforced with 20 wt% orange peels ash particles (OPAp) were prepared by compression moulding. Thermogravimetric analysis (DTA/TGA) was conducted on the HDPE/orange peels ash particle composite to clarify the effect of OPAp on the thermal decomposition behaviour of the resultant composite. The values of the activation energy for thermal decomposition reflected the improvement of the thermal stability of the HDPE/OPAp composite. The research has established that the orange peel ash particles are beneficial to act as thermal decomposition resistant and reinforcing particles in the HDPE matrix composite.

Also Idris **[8],** investigated the suitability of maize cob particles and recycled low density polyethylene (RLDPE) as binders for particleboard manufacturing. The board was produced by varying RLDPE from 30-70 wt. % at 10 wt. % interval. The microstructure, physical (thickness swelling (TS), water absorption (WA)), and mechanical (modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond strength (IB)) properties of particleboards were determined. The results showed that the WA and TS values were moderate, the MOR exceed the minimum requirements of the European standards, for general purpose boards. They concluded that maize cob particles and RLDPE can be used as a substitute to wood- formaldehyde based particleboard for general purpose applications.

The level of effort so far made on the review of literature on this ongoing research has not included information on the use of mango shell particle and recycled high density polyethylene in the production of particleboard composites. Hence the justification of embarking on this project to fill the gap.

2.1 Particleboard

Particleboard is an under coated flat panel product made from wood particles bonded together with resins. Tight compaction of the product allows clean machining and very fine surface finish **[10]**. The binder is a chemical material that binds the particles together to produce particleboard or medium density fibre board. It is a sticky substance from plants and certain trees (i.e. a similar substance made synthetically, and used in plastics) **[8]**.

2.2 Parameters Affecting Board Properties

2.2.1 Density

The density of raw material has a profound effect on the physical properties of particleboard. Low density wood species produce particleboards with higher strength compared to those of higher density **[11].** This can be explained by the fact that low-density wood has a relatively high compaction ratio when hot-pressed into a board, resulting in better contact among the particles. The density of the resultant panel after hot pressing also affects the mechanical properties of the board. At the hot press, interaction between heat, pressure and moisture leads to a non-uniform deformation of the materials and subsequently an uneven density distribution along the thickness of the board that is formed.

2.2.2 Moisture Content

The moisture content (MC) and its distribution during manufacture and within the thickness of the formed mat plays a very important role in panel mechanical and physical properties. A higher MC in the face layer will result in a higher densification towards the surface **[12].** There is an upper limit after which additional increases in moisture content will result in blow outs within the panel. Higher surface densities will have a positive impact on bending strength and stiffness **[12].** Conversely, raw material of uniform MC will exhibit a lower density toward the surface resulting in lower mechanical properties. Several researchers have studied the influence of mat MC on particleboard properties **[12]; [13].**

2.2.3 Particle Size

Particle geometry describes shape and size dimensions of particles used in particleboard production **[14].** The parameters create a significant impact on the properties of the boards. Particle size plays a more important role in the development of board properties than the actual mechanical properties of the panels **[14].**

2.3 Agricultural Wastes as Particleboard Materials

Particleboards made from agricultural waste may be one of the best and effective ways of conserving the environment. Every year with production of food, and equal or more amount of biomass as by product in the form of stalk, leaves and husk are produced. A portion is used as animal feed and for some miscellaneous jobs. The remaining portion along with weed plant may be potential sources of raw materials for manufacturing particleboards. The cost of this substitute is high due to use of resins. As for analysis, resins consume 60 % of the cost of particleboard. Thus, eliminating or reducing the use of resin will bring down the cost of particle boards and they can be made available at a cheaper price **[14].**

III. MATERIALS, EQUIPMENT AND METHODS

3.1 Materials

Mango shells were collected randomly from the streets of Kaduna metropolis, while the waste high density polyethylene (HDPE) yoghurt bottles were collected from '*youghurt'* sellers also in the metropolitan city of Kaduna State, Nigeria. After washing the materials thoroughly with tap water and sodium hydroxide, the mango seeds were removed from the shells manually, the shells were oven-dried at about 140 ^{0}C for two hours and then ground into powder, while the yoghurt bottles were dried and manually cut into small pieces.

- **Equipment**

The equipment that were used in this study include: electrical hydraulic press, two roll mill machine, Charpy impact testing machine, Hounsfield tensometer, laboratory balance, metal moulds, scanning electron microscope/energy dispersive spectroscope (SEM/EDS), film shredder, **E**nerpac universal materials testing machine and X-ray fluorescent spectrometer (XRF).

3.3 Methods

3.3.1 Characterization of the Mango Seed Shells

- **The processing of the mango seed shells (MS) into mango shell particles (MSP) -** This involves collection, treatment in NaOH solution, drying and grinding of the waste to form mango shell powder.

- **The sieve analysis of the particles** - The particle size analysis of the mango shell was carried out in accordance with BS1377:1990 **[17].** 100g of the particles was placed unto a set of sieves arranged in descending order of fineness and shaken for 15 minutes which is the recommended time to achieve complete classification. The particles retained in the BS 420 µm particle size was used for the study **[17].**

3.3.2 Sample Preparation

Metal moulds were used in the production of the particleboard composite samples. Each mould had a cavity that accommodated the board composite samples. The dimensions and shapes of cavities were made according to the size and shape of the samples as per ASTM Standard D 638-90 for tensile testing and ASTM Standard D 790-97 for flexural testing (ASTM, 2000). The particles and the binder were mixed by compounding into a homogenous mixture at 130 ^{o}C using two roll mills. The compounded mixture was compressed at 150 ^{o}C for fifteen minutes at a pressure of 10 MPa supplied by an electrically heated hydraulic press, in accordance with the **[17],** to produce the particleboard composites. The compounding and pressing was carried out using a two roll mills and pressing machines. The RHDPE was varied from 30-70 wt. % at interval of 10 wt. %. Five different types of composites were produced using 420µm particle size of MSP in RHDPE binder. The formulation is as shown in Table 3.1 below:

Table 3.1: Formulation of the composite using MSP/RHDPE

Designation	Mango shell particles (%wt.)	RHDPE (%wt.)
PBC30	30	70
PBC40	40	60
PBC50	50	50
PBC60	60	40
PBC70	70	30

3.3.3 Microstructural Analysis

The Scanning Electron Microscope (SEM) model JEOL JSM-6480LV was used to identify the surface morphology of the board composite samples.

3.3.4 Determination of Density

The basic method of determining the density of board composite samples was by measuring the mass and volume of the sample used. The density of this sample was estimated from equation **[18]:**

$$Density = \frac{Mass}{Volume} \quad (3.1)$$

3.3.5 Thickness Swelling (TS) and Water Absorption (WA) test

Specimen with dimensions of 50 mm x 50 mm were prepared for evaluation of the thickness swelling. The thickness at the middle of the test specimen was measured with a micrometre and placed into water in parallel and soaked for 24 hours before further measurement of the thickness was made. The Thickness swelling rate (TS) was determined using the following formula **[5].**

TS_{24} =, (3.2)

where:

TS = the thickness swelling rate (%), t∘ = the initial thickness,

t_{24} = the thickness measure after 24 hour.

The percentage of the water absorption (WA) was calculated using the expression of the form **[5].** WA = , (3.3)

where:

WA (t) = the water absorption (%) at time t, Wo = the initial weight, and

W (t) = the weight of the sample at a given immersion time t.

3.3.6 Static Bending Test

Bending specimen each with a section of 50 mm wide by 275 mm long were cut from various samples of the particleboard under investigation. A concentrated bending load was applied at the centre with a span of 15 times the thickness of the specimen. The bending modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated from load deflection curves according to the following formula **[5]:**

(3.4)

. (3.5)

where:

P_b = the maximum load (N), P_{bp} = the load at the proportional limit (N),

Y_p = the deflection corresponding to P_{bp} (mm), b = the width of the specimen (mm),

h = the thickness of the specimen (mm), and L = the span (mm).

3.3.7 Internal Bond Strength

The tensile strength perpendicular to the surface was determined using three conditioned specimen 50 mm x 50 mm from each particleboard. The rupture load (*Ps*) was determined, and internal bond strength calculated using the following formula **[10].**

. IB = . (3.6)

where:

Ps = the rupture load, and *l* = the length of the specimen.

3.3.8 Impact Strength (Scatter index test)

The reliability of a material can be determined by measuring its resistance to fracture, either ductile or brittle and fracture toughness **[15].** However, scatter-index tests reveal both toughness and fracture types.

3.3.9 Hardness Test

The hardness of a composite is the relative ability of the material surface to resist indentation by an indenter of specified dimension under a specified load. Hardness test of the board was carried out to determine the materials ability to resist plastic deformation**.**

IV. RESULTS AND DISCUSSION

4.1 RESULTS

Figures 4.1 to 4.8 and table 1 toA7 show the physical and mechanical properties of the particleboards and plate 4.1 to 4.5 showed the microstructural examination results of the various tests carried out on the developed composite samples of particleboard.

4.1.1 Physical and Mechanical properties of the developed particleboard

TABLE 1: Results of Density for MSP/RHDPE Composite

Sample Number	MSP/HDPE Composite (Wt %)	Mass (g)	Volume (cm^3)	Density (g/cm^3)
PBC30	30/70	8.91	9.0	0.99
PBC40	40/60	12.48	13.0	0.96
PBC50	50/50	10.34	11.0	0.94
PBC60	60/40	10.12	11.0	0.92
PBC70	70/30	12.65	13.9	0.91

TABLE 2: Results of Thickness Swelling and Water Absorption for MSP/RHDPE Composite

Sample Number	MSP/HDPE Composite (Wt %)	Initial thickness (mm)	Final thickness (mm)	Thickness swelling, TS (%)	Initial mass (g)	Final mass (g)	Water absorption, WA (%)
PBC30	30/70	4.3	4.45	3.5	8.7312	10.1000	15.7
PBC40	40/60	4.9	5.11	4.2	8.8101	10.4433	18.5
PBC50	50/50	5.0	5.22	4.4	10.6285	12.7029	19.4
PBC60	60/40	4.8	5.02	4.7	10.9255	13.6201	24.6
PBC70	70/30	5.1	5.38	5.5	13.5341	17.1071	26.4

TABLE 3: Results of Impact Energy for MSP/RHDPE Composite

Sample Number	MSP/HDPE Composite (Wt %)	Sample Thickness (mm)	Energy (J)
PBC30	30/70	4.1	3.5
PBC40	40/60	4.0	4.5
PBC50	50/50	4.0	4.9
PBC60	60/40	4.0	2.4
PBC70	70/30	3.8	0.9

TABLE 4: Results of Bending Modulus of Elasticity for MSP/RHDPE Composite

Sample Number	MSP/HDPE Composite (Wt %)	h (mm)	b (mm)	P_{bp} (N)	Y_{p} (mm)	MOE (MPa)
PBC30	30/70	4.0	50.0	2	1.5	2250
PBC40	40/60	3.9	50.3	12	5.1	2450
PBC50	50/50	4.0	50.5	3	2.7	2340
PBC60	60/40	4.2	49.0	6	1.5	1735
PBC70	70/30	4.0	50.5	36	2.4	1705

TABLE 5: Results of Bending Modulus of Rupture (MOR) for MSP/RHDPE Composite

Sample Number	MSP/HDPE Composite (Wt %)	h (mm)	b (mm)	P_b (N)	MOR (MPa)
PBC30	30/70	4.0	50.0	3	10.45
PBC40	40/60	4.0	50.3	30	11.49
PBC50	50/50	3.8	50.5	18	11.28
PBC60	60/40	4.2	49.0	9	8.40
PBC70	70/30	4.0	50.5	57	5.91

TABLE 6: Results of Internal Bond Strength for MSP/RHDPE Composite

Sample Number	MSP/HDPE Composite (W%)	b (mm)	l (mm)	P_s (N)	IB (MPa)
PBC30	30/70	49.5	50.0	990.0	0.40
PBC40	40/60	50.1	49.8	1447.09	0.58
PBC50	50/50	48.8	50.0	1342.00	0.55
PBC60	60/40	50.0	50.1	1127.25	0.45
PBC70	70/30	51.0	49.5	908.82	0.36

TABLE 7: Results of Hardness values for MSP/RHDPE Composite

Sample Number	MSP/RHDPE Composite (Wt %)	Hardness (HRB)
PBC30	30/70	3.88
PBC40	40/60	5.17
PBC50	50/50	5.83
PBC60	60/40	6.79
PBC70	70/30	9.00

4.2 DISCUSSION OF RESULTS

4.2.1 Density

The density, thickness swelling (TS) and water absorption (WA) of the particleboards are displayed in Figures 1-3. The values obtained for the thickness swelling (TS) and water absorption (WA) of the particleboards are high. This is due to the absence of water repellent agents in the particleboard manufacturing.

Fig 1 Variation of density versus percentage of RHDPE

Fig 2: Variation of Thickness Swelling versus percentage of RHDPE

Fig 3: Variation of water absorption versus percentage of RHDPE

The result of density measurements on the samples of particleboard are shown in Figure1 and Table 1. The incorporation of mango shell particles therefore decreases the density of RHDPE matrix. At 30 % wt. RHDPE, the density is 0.9 g/cm^3, and at 70 % wt. RHDPE, the density is 0.99 g/cm^3. The density profile of a particleboard is dependent on the particle configuration, moisture distribution in the mat, hot press temperature and rate of closing, binder reactivity and the compressive strength of the particles **[17], [19].** Increasing the board density decreased the TS and WA for 24 hour immersion (Figures2-3). This is due to low porosity and difficult diffusion on the high density particleboard. The swelling that occurs is the sum of two components, namely, swelling by hygroscopic particles and the release of compression stresses imparted to the board during the pressing of mat in the hot press as posited by **[7].** The release of compressive stresses known as spring-back is not recovered when the board is in dry state.

4.2.2 Thickness Swelling

Figure 2 and Table 2 show the results obtained for thickness swelling (TS) of the produced RHDPE/MSP particleboard. Thickness swelling of the mango shell board increases as the weight fraction of mango shell particles in the matrix of the composite increases and vice versa. At 30 % wt. RHDPE, the thickness swelling is 5.5 % and at 70 % wt. RHDPE, the thickness swelling is 3.5 %. Based on European Standards, particleboard should have a maximum thickness swelling value of 15% for load-bearing applications **[5].** The thickness swelling values of boards produced fall within the required specification.

In general, the mango shell particles affected the WA and TS properties negatively. Similar results were found by Ntalos et al**[20]** for other agro-based particleboards. Decreasing the binder increased the WA and TS of particleboards.

4.2.3 Water Absorption

Figure 3 and Table 2 show the water absorption of the developed composite samples of particleboard. This property increases with increase in mango shell particles (MSP) content and decreases with increase in RHDPE binder. This is due to the hydrophilic nature of the particles (high water absorption). At 30 % wt. RHDPE, the water absorption is 26.4 % and at 70 % wt. RHDPE, the water absorption is 15.7 %. The results obtained here are far better than that obtained for wood based particleboard (BSI, 2003). The lower water absorption obtained for the developed MSP/RHDPE particleboard may also be attributed to the chemical treatment of the shells with NaOH solution before grinding. The hydrophilic nature of the mango shells (high moisture absorption) is incompatible with hydrophobic polymer matrix and has a tendency to form aggregates **[21].** These hydrophilic mango seed shells exhibit poor resistant to moisture, which lead to high water absorption, subsequently resulting in poor tensile properties of the mango shell particulates reinforced particleboards.

4.3 Mechanical Properties of the developed particleboard

4.3.1 Impact Strength

Figure 4 and Table 3 show the results obtained for impact strength measurement on the developed MSP/RHDPE particleboard. The results obtained show that the impact strength of the board composites increased with increase in RHDPE binder addition as depicted in Figure 4.4. At 30 % wt. RHDPE, the impact strength is 0.9 J and at 70 % wt. RHDPE, the impact strength is 3.5 J. The steep increase in the impact strength of the produced MSP/RHDPE board could be attributed to the presence of particles well bonded by the RHDPE binder. Similar observation was made by Orsar **[17]** for other agro-based particleboards. This factor leads to increase in impact energy. High strain rates or impact loads may be expected in many engineering applications of particleboard composite materials.

Fig. 4: Variation of impact strength versus percentage of RHDPE

Fig. 5: Variation of hardness values versus percentage of RHDPE

4.3.2 Hardness Values

Figure 5 and Table 7 shows the hardness values obtained for the developed mango shell particleboards. The hardness number of the mango shell particleboards decreases as the percentage of RHDPE binder increases and vice-versa. This may be due to the increase in sample density of the mango particles in the matrix of the composite. In comparison with little amount of reinforced RHDPE matrix, a substantial improvement in hardness number was obtained in the little reinforced polymer matrix. This is in line with the earlier research of Kozlowski and Helwig **[15].**

Fig. 6: Variation of Modulus of Rupture versus percentage percentage of RHDPE

Fig.7: Variation of Iinternal Bond Strength versus percentage of RHDPE

Fig.8: Variation of Modulus of Elasticity versus of RHDPE

4.3.3: Modulus of Rupture

Figure 6 and Table 5 shows the results obtained for modulus of rupture (MOR) measurement on the developed mango shell particleboard. The MOR ranged from 5.9 to 11.49 N/mm^2 as shown in Figure 6. The MOR requirement for general purpose boards is 11.5 N/mm^2 **[7].** In addition, increasing the RHDPE binder increases the MOR up to 60 wt. %, but beyond this level no further increase in MOR was observed.

4.3.4 Internal Bond Strength

Figure 7 and Table 6 show the results obtained for internal bond strength (IB) measurement on the developed mango shell particleboard. The range of data obtained for IB was from 0.36 to 0.60 N/mm^2 as shown in Figures 7. The IB requirements of 0.24 N/ mm^2 for general purpose boards, 0.35 N/mm^2 for interior fitments, load-bearing boards and 0.50 N/mm^2 for heavy duty load bearing boards according to the European Standards, BSI, (2003): BS EN 312:2003. The internal bonding strength obtained is comparable with values reported by Chew et al **[1] and Kuo et al [4].** The mango shell particleboard surpassed the mechanical strength requirements for general purpose applications specified by European standard. All of the particleboards produced here are within the recommended standard for general purpose, interior fitments, load-bearing boards and heavy-duty load bearing boards.

4.3.5 Modulus of Elasticity

The values obtained for modulus of elasticity (MOE) is shown in Figure 8 and Table 4 Tensile modulus and internal bonding strength measurements are among the most important indicators of strength in a material and are most widely specified property. Tensile modulus is an indication of the relative stiffness of a material; it is a measurement of the property of a material to withstand forces that tend to pull it apart and to determine to what extent the material stretches before breaking. The improvement in tensile modulus was noticed with the developed particleboards. These indicate that use of mango shell particles and RHDPE in production of the particleboards improved the load bearing capacity of the board. Similar observations have been reported by

Orsar **[17], Ntalos et al [20] and Wasylcis [22]** for other particleboards. In addition, the developed particleboards deform less until maximum load, which gives a higher tensile modulus. The increase in Young's modulus with increasing RHDPE is expected since the addition of RHDPE to mango shell particles increases the stiffness of the particleboard. The presence of polar group in the RHDPE may contribute to electrostatic absorption between RHDPE and the agro particles.

4.4 Microstructural Examination (SEM)

The microstructures of the particleboard composites by SEM are shown in Plate 4.1- 4.5. Microstructural studies of the particleboard composites by Scanning Electron Microscope (SEM) with Energy Dispersive Spectroscopy (EDS) revealed a uniform distribution of the mango shell particles with the RHDPE binder. SEM/EDS combine top quality imaging functionality with elemental analysis in the same chamber. The distribution of the particles is influenced by the compounding of the particles and the binder which resulted to good interfacial bonding as shown in the developed particleboards in plate 4.1 -4.5

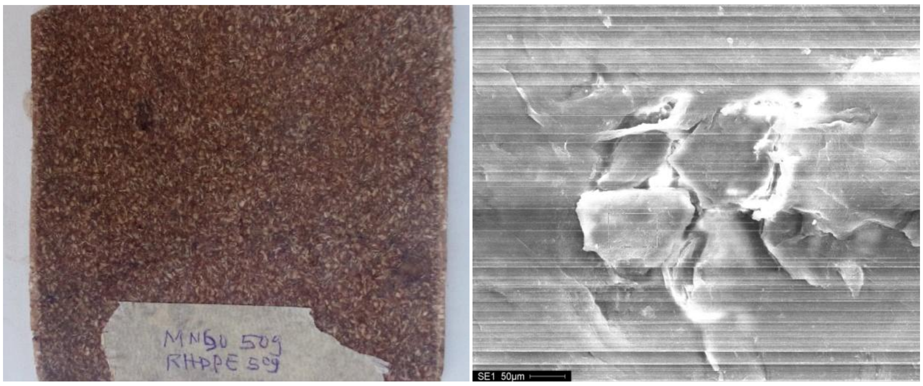
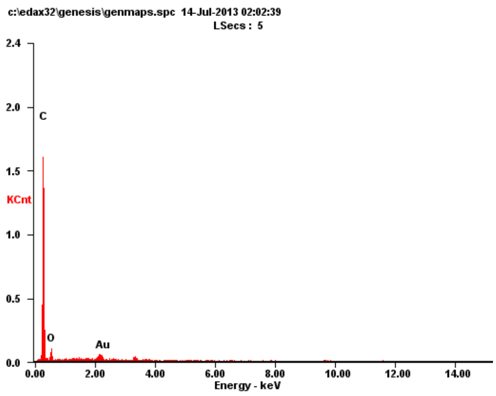
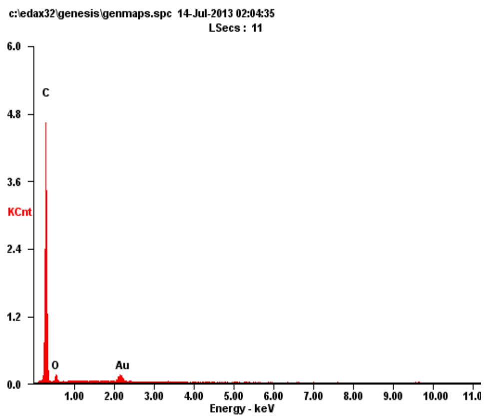


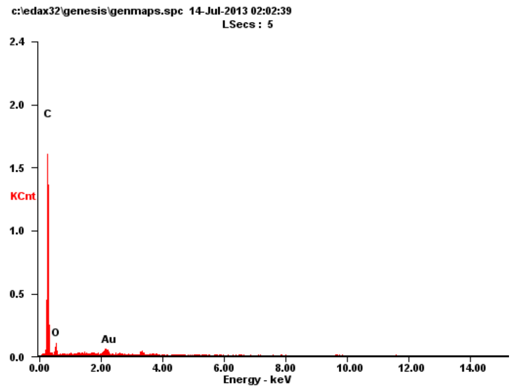
Figure 4.9: Sample of a mango shell particleboard with RHDPE

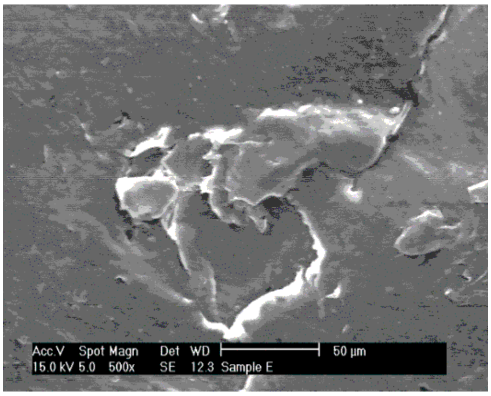


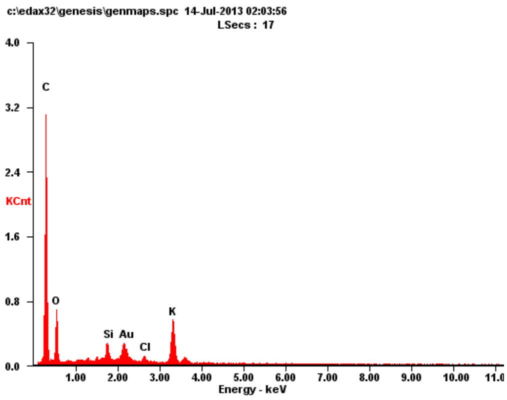
Mag: 500X (a) (b)

Plate 4.1: SEM Microanalysis of 70 % wt. MSP composite (a) Image, and (b) EDS





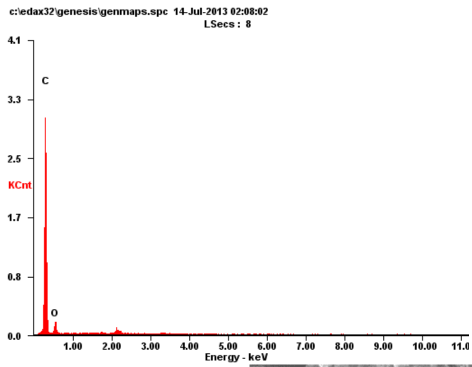


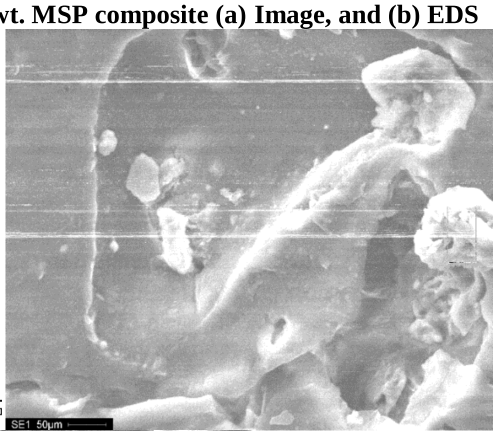


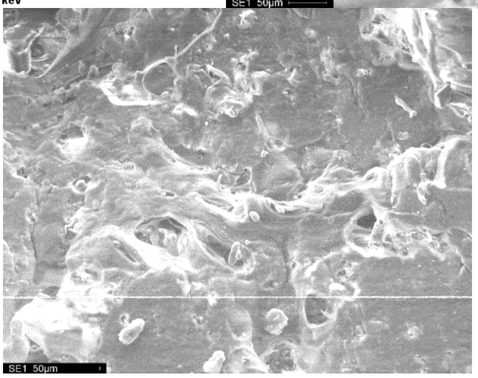
Mag: 500X (a) (b)

Mag: 500X (a) (b)

Plate 4.2: SEM Microanalysis of 60 % wt. MSP composite (a) Image, and (b) EDS

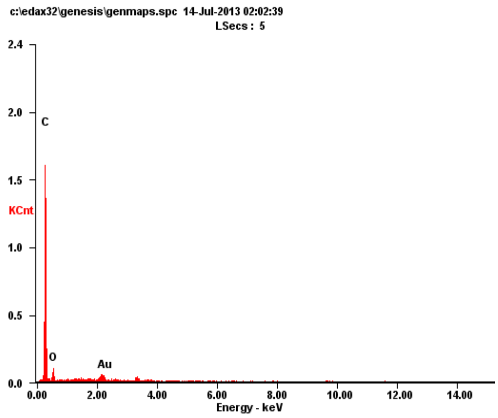


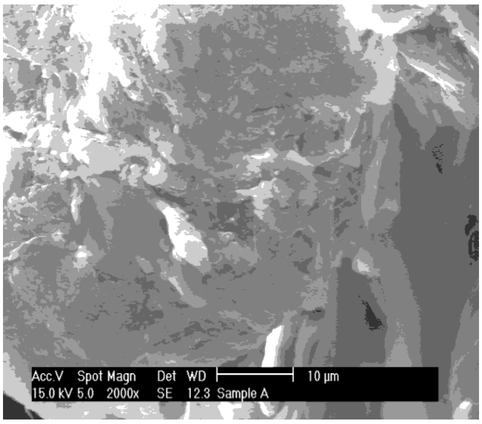




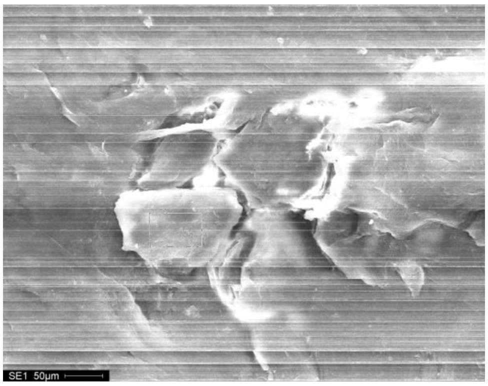
Mag: 500X (a) (b)

Plate 4.3: SEM Microanalysis of 50 % wt. MSP composite (a) Image, and (b) EDS





Mag: 2000X (a) (b)



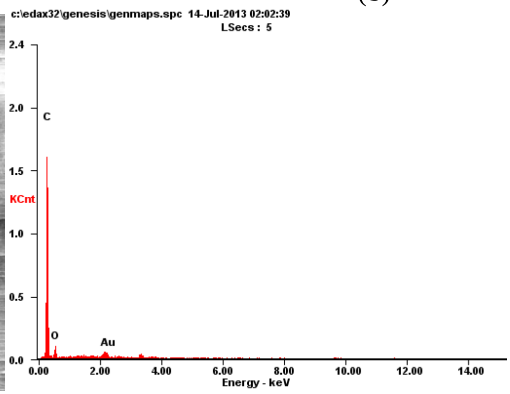


Plate 4.4: SEM Microanalysis of 40 % wt. MSP composite (a) Image, and (b) EDS

Mag: 500X (a) (b)

Plate 4.5: SEM Microanalysis of 30 % wt. MSP composite (a) Image, and (b) EDS

The microstructure clearly shows that when the mango shell particles was added to the RHDPE binder, morphological change in the structure take place. The microstructure reveals that there are small discontinuities and a reasonably uniform distribution of mango shell particles and the RHDPE binder. The mango shell particles phase is shown as white phase, while the resin (binder) phase is dark. Similar examination was reported by Idris et al **[9] and Orsar [17]** for other agro-based particleboards. The mango shell particles are embedded within the amorphous matrix composed of randomly distributed matrix planar boundaries. The surface of the mango shell particles is smooth indicating that the compatibility between particles and the resin (binder) was good. It can be seen that the mango shell particles are not detached from the RHDPE surface as the weight fraction of mango shell particles increased in the resin (binder);

4.5 Comparative Analysis

The particleboards made with 60 wt.% RHDPE reinforced with 420 µm particle size mango shell particles were compared with that of Flax-board made with flax fibers and urea resin glue (Urea Formaldehyde) and that of Medium Density Fiber-board (MDF) made of wood composite materials (Table 8). The results are in close agreement. This study shows that mango shell particles can work well with RHDPE when used in the production of particleboards. Also, different contents of RHDPE had significant influence on mechanical properties of particleboards. Generally, the boards produced with the mango shell particles at 50-60 % RHDPE binder gave best results and conform to the BSI specifications of density particleboards for general purpose board requirements like paneling, ceiling, partitioning e.tc (interior decoration).

Table 8: Comparison of the result findings with existing ones

Properties	MDF		Flax-board	Present study MSP (420 µm) at 60wt % RHDPE
	(www.finsa.es)	(www.spanogroup.be)	(www.linex-pg.nl)	
Board density (g/cm^3)	0.85	0.60-0.65	0.35-0.8	0.96
Internal bonding strength (N/mm^2)	0.90	0.40 – 0.45	0.1	0.58
Modulus of elasticity (N/mm^2)	NA	1400-1700	750	2450
Modulus of Rupture	NA	NA	NA	11.49
Thickness swelling (%)	15	11-20	NA	13
Hardness	NA	NA	NA	5.17

Note: Flax-board is a particle-board composite of flax fibres and urea resin glue (Urea Formaldehyde). Medium Density Fibre-board (MDF) is a wood composite material made by wood fibres. NA: Not Available

V. CONCLUSION

The present research centered on the development and characterization of particleboard composites made using mango shell particles as reinforcement in RHDPE matrix (binder). From the results obtained, the following conclusion can be drawn:

- The work shows the successful development of particleboards using mango shell particles (MSP) as reinforcement and recycled high density polyethylene (RHDPE) binder by simple compression molding technique.
- The density increased as the percentage of binder increases in the particles.
- The percentage of thickness swelling and water absorption increased as the weight fraction of the RHDPE binder decreases.
- The tensile properties obtained are in agreement with the results obtained from the analysis of impact strength.
- The uniform distribution of the particles and the RHDPE binder in the microstructure of the board composites, the board density and particle size of the particles are the main causes of changes in the mechanical and physical properties of boards.
- The developed particleboards will find application for general purpose requirements like paneling, ceiling, and partitioning, since the properties of particleboards used in this area compared favorably with the properties of the developed boards at 50-60 wt. % RHDPE binder.

VI. RECOMMENDATIONS

In the course of the investigation, new areas of research have been identified.

- Further work should be done on chemical modification methods like coupling agents and graft co-polymerization, aimed at improving the tensile properties of the particleboards.
- Work should be done on different particle sizes to determine the effect of particle size on the mechanical and physical properties of mango MSP/RHDPE particleboards.

REFERENCES

[1] Chew L.T, Nurulhuda.M.N, Ong C.L and Rahim.S., (1991): "Particleboard from some plantation species". Pp. 708−724 in Abod SA et al. (Eds.) Proceedings of a Regional Symposium on Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia. 5−9 June 1989, Serdang. Universiti Putra Malaysia, Serdang.

[2] Younquist, Y., Watanabe, H and Takeda, S., (1994): "Rubberwood characteristics of its supply and development of its utilization". Forest Research 71: 65−70.

[3] MacCleery, R., (1995): "Resiliency, the trade mark of American forests". Forest Prod. J. 45, 19-28. Medium Density Fiber-board Properties. Accessed March 2, 2014 from http://www.spanogroup.be

[4] Kuo, M., Adams, D., Myers, D., Curry, D., heemstra, K., Smith, J and Bian, Y., (1998): "Properties of wood agricultural fiberboard bonden with soybean-based adhesives". Forest Prod. J. 48 (2), 71- 75.

[5] BSI (2003): BS EN 312:2003: "Particleboards Specifications". The British Standards Institution, London.

[6] Hall, H.J., Gertjajensen, R.O., Schmidt, E.L., Carl, C.G and DeGroot, R.C (1984): "*Preservative effect on mechanical and thickness swelling properties of Aspen wafer board"*. In: Proceeding of a Workshop on Durability of Str. Panels. Pencacola, Florida, USA, 234-247.

[7] Liu, J.Y. and Mcnatt, J.D., (1991): "Thickness swelling and density variation in aspen flakeboards". Wood Sci. Technol. 82, 25 -33.

[8] Han, G., Zhang, C., Zhang, D., Umerra, D and Kawai, S., (1998): "Upgrading of urea formaldehyde bonded reed and wheat straw particleboard using silane coupling agents". J. Wood Sci. 44, 282- 286.

[9] Idris, U.D., Aigbodion. V.S., Gadzama. R.M and Abdullahi.J (2011):"Eco-Friendly (Watermelon Peels) Alternatives to Wood-based Particleboard Composites". *Pacific Journal of Science and Technology*. 12(2):112-119.

[10] ASTM E290 (2000) Physical Testing Standards and Mechanical Testing Standard.

[11] Wong, E.D., Yang, P., Zhang, M., Wang, Q., Nakao, T., Li, k.F and Kawai, S., (2003): "Analysis of the effects of density profile on the bending properties of particleboard using finite element method (FEM)". *European Journal of Wood and Wood Products* 61, 66–72.

[12] Han, G., Wu, Q. and Wang, X., (2006): "Stress-wave velocity of wood-based panels". Effect of moisture, product type, and material direction. *Forest Products Journal* 56, 28.

[13] Papadopoulos, A., (2006): "Property comparisons and bonding efficiency of UF and PMDI bonded particleboards as affected by key process variables". *BioResources* 1.

[14] Suchsland O. and Woodson G.E., (1990): "Fiberboard manufacturing practices in the United States". Agriculture handbook no. 640. Washington, DC: USDA Forest Service; 34.

[15] Kozlowski, R and Helwig, M., (1998): "Lignocellulosic polymer composite". In: Prasad, P.N. (Ed.), Science and Technology of Polymers and Advanced Materials. Plenum Press, New York, pp. 679-698.

[16] Lee S.Y, Yang H.S, Jeong C.S Lim B.S and Lee J.N (2004): "Creep behavior and manufacturing parameters of wood flour filled polypropelene composites".

[17] Orsar, F.A., (2014). "Suitability of Orange Peels particles, Banana Peels particles and Recycled low Density Polyethylene composites for Particleboard manufacturing". A thesis submitted to the Department of Mechanical Engineering, Ahmadu Bello

University, Zaria, in partial fulfillment of the requirements for the award of the Degree of Masters of Science in Mechanical Engineering.

[18] BSI (1993b): BS EN 310:1993: "Wood-based panels—Determination of Modulus of Elasticity in Bending and of Bending Strength". The British Standards Institution, London.

[19] Aigbodion V.S, Hassan. S.B and Agunsoye J.O (2011): "Effect of bagasse ash reinforcement on dry sliding wear behaviour of polymer matrix composites". Materials and Design 33 (2011), 322–327.

[20] Ntalos, G.A and Grigoriou, A.H (2002): "Characterization and utilisation of Wine prunings as a wood substitute for particleboard production". Industrial Crops and Products 16(1), 59/68

[21] Xu, F and Sun R. C (2006): "Comparative study of alkali–acidic organic soluble hemicelluloses polysaccharides from sugarcane (bagasse)", Composites B, 1234-1238.

[22] Wasylciw, W., (1999): "The utilization of industrial hemp stalks in composite panels. Proceedings of the Meeting of the Eastern Canadian Section of the Forest Products Society". May 19-20, Winnipeg, Manitoba Wood Panel Industries Federation, 2000. *Code of Practice for the Application of Wood Chain of Custody Criteria to Product Environmental Labelling in the Sawmillong and Wood Panel Board Sectors*. WPIF/UKFPA/1-2000.

Adewuyi Micheal Abolaji. "Suitability of Mango Seed Shell Particles and Recycled High Density Polyethylene (RHDPE) Composites for Production of Particleboard ." International Journal of Engineering Research and Applications (IJERA), vol. 6, no. 8, 2017, pp. 314–325.