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Strength and Micro-Structural Properties of Wood Chips Composite Panel

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Abstract

Global warming primarily due to deforestation has led to the development of new materials to substitute felling of trees by wood-based industries. The utilisation of wood chips and cassava starch for the production of particle board was the thrust of this research. The chip sizes of 0.85 and 1.7 mm, dosage and types of binders (cassava starch, urea formaldehyde and Glutaraldehyde modified cassava starch) were the variables. The ratio of wood chips to the binders was 1.0:1.5. The boards were formed in rectangular moulds. Water absorption, thickness swelling, flexural tests and material characterisation (using scanning electron microscope (SEM)) were carried out. Data collected was subjected to analysis of variance. The result obtained was subjected to analysis of variance. The particleboards produced with modified cassava starch had the best mechanical properties with the modulus of elasticity (MOE) ranging from 5.90 to 32.32 N/mm² but had a higher thickness swelling values ranging from 3 to 59.37%. There was a significant difference ($p < 0.01$) between the boards manufactured using plain starch and modified starch. These tests results have shown that wood chips, plain cassava starch and modified cassava starch are sources of raw materials in the production of particleboard. The developed particleboard can be used for paneling, partitioning and ceilings.

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Introduction

The demand for wood composites has been increasing as timber resources in forests are declining. A large amount of wood consumption could mean a high worldwide deforestation rate that can cause negative impacts on the environment if not reduced (Onuegbu, 2010). Particleboard is a wood-based board product which is manufactured under pressure and heat with the help of wood particles or other lingo-cellulosic materials and an adhesive. It is an inexpensive alternative to solid wood paneling and has emerged as a versatile substitute for wood in many applications such as in building construction, decoration, air conditioner duct covering, door panel inserts, wall panel and floor-ceiling tiles (Rafael *et al.*, 2014; Elbadawi *et al.*, 2015; Akpenpuun *et al.*, 2017). Wood particleboards are manufactured as panels from dry wood particles that have been sprayed or dusted with a binder resin and are bonded together with pressure and heat. Particles for the boards can be made from almost any type of wood, whether whole logs or wood residues such as trimmings and shavings from lumber or plywood manufacturing. Many species are used, although the lower density woods are preferred (Elbadawi *et al.*, 2015).

The global production of particleboard has increased in recent years to more than 23 million cubic meters per year as a result of the increase in global consumption.

Particleboard has found typical applications in flooring, wall and ceiling panels, office dividers and furniture. Currently, particleboard provides industrial users the consistent quality and design flexibility needed for the rapid and efficient production of quality consumer products (Elbadawi *et al.*, 2015). Starch can be obtained locally from most carbohydrates that contain high quantity of starch such as corn, rice, potatoes. However, starch is mostly gotten from Cassava. The Cassava starch is mostly used as laundry stiffener in Nigeria. Starch can either be stand-alone or modified (Mohd *et al.*, 2013; Baishya and Maji, 2014). Modified starch is obtained by diluting starch with an organic compound such as Glutaraldehyde or Urea Formaldehyde. Glutaraldehyde is used both as a disinfectant and medication in hospitals (Wang *et al.*, 2007; Sheng *et al.*, 2015).

The objective of this study was to evaluate particleboard made from wood chips using stand-alone cassava starch and modified cassava starch (with Glutaraldehyde and Urea formaldehyde) as binders by determining some physical and mechanical characteristics of the boards.

Materials and Methods

Materials Acquisition and Preparation

Wood shavings, urea formaldehyde, Glutaraldehyde, and cassava starch (the binder) were obtained at Surulere, Ilorin, Kwara State. The wood shavings were screened using 0.85

and 1.7mm sizes sieves and were air-dried to reduce the moisture content to about 3–5%. The particles retained on the sieve were used for the particleboard preparation. The starch was initially dissolved in warm water (30°C) and then in boiling water (100°C) to form a colloidal solution. The urea formaldehyde and Glutaraldehyde were used to modify the starch. The mouldswere made from wood and rectangular in cross-section (610 × 300mm).

Production of the Particleboards

The wood chips were sieved and sorted into two different sizes (0.85 and 1.7 mm) using the standard sieve sizes. Shown in Table 1 is the mix design for each of the particleboard sample, while Figure 1 is one of the manufactured boards ([P1-D (1.5)-MCS]).

Table 1: Particle board mix design.

S/No.	Sample	Particle Size, mm	Binder / Dosage, mL	Volume of Additive / Volume
1	[P1-D (1.5)-MCS]	0.85	modified cassava starch (MCS) / 1.0	Glutaraldehyde solution / 500mL
2	[P1-D (1.5)-SA]	0.85	binder starch alone (SA) / 1.2	Urea formaldehyde / 300mL
3	[P1-D (2.5)-MCS]	0.85	modified cassava starch (MCS) / 2.4	Glutaraldehyde / 100mL
4	[P1-D (2.5)-SA]	0.85	modified cassava starch (MCS) / 2.0	Urea formaldehyde / 500mL
5	[P2-D (1.5)-MCS]	1.70	modified cassava starch (MCS) / 2.0	Glutaraldehyde / 500mL
6	[P2-D (1.5)-SA]	1.70	starch alone (SA) / 1.2	Urea formaldehyde / 300mL
7	[P2-D (2.5)-MCS]	1.70	modified cassava starch (MCS) / 2.40	Glutaraldehyde = 100mL
8	[P2-D (2.5)-SA]	1.70	starch alone (SA) / 2.0	Urea formaldehyde = 500mL

The weight of wood chips in all samples = 1kg



Figure 1: Particleboards

Water Absorption and Thickness Swelling Test

Water absorption and thickness swelling tests were carried out in accordance with American standard test methods for evaluating properties of wood-based fibre and particle panel material (ASTM D 1037 - 23, 2012) using 70 x 70 x 35 mm³ sample size. The difference in the weights of the oven dried and wet samples after 2 hours and 24 hours were recorded respectively. Water absorption and thickness swelling were determined using expression 1.

$$\text{Water absorption} = \frac{\text{wet weight/thickness} - \text{dry weight/thickness}}{\text{dry weight/thickness}} \times 100\% \dots\dots\dots 1$$

Flexural Strength Test.

The flexural strengths of the specimens were determined in accordance with American standard test methods for evaluating properties of wood-based fibre and particle panel material (ASTM D 1037 - 33, 2012). The modulus of

elasticity (MOE) and modulus of rupture (MOR) was calculated from load-deflection curves of a universal testing machine (Testometric M500-50AT) using equations 2 and 3.

$$\text{MOR} = \frac{3PL}{2bh^2} \quad 2$$

$$\text{MOE} = \frac{PL^3}{4bh^3Y} \quad 3$$

where, P = maximum load, L = span, h = thickness, b = width, Y = deflection

Scanning Electron Microscope

The scanning electron microscope was used to carry out the SEM test using the corks of plastic bottles and then tested using a JEOL JSM-7600F. The dimensions of samples for the SEM test was 20 x 2.5 x 10.5 mm and was carried out on type R (modified cassava starch) and type B (starch alone). The SEM images were taken at three different magnification sizes x10000, x11000 and x12000 and x6000, x8000 and x10000. SEM test was determined in accordance with ASTM E986 – 04, 2017.

Results and Discussions

Water Absorption

The result of water absorption is presented in Table 2. Average water absorption of the samples ranged from 32.66 to 140.74% for 2 hours' immersion and ranged from 33.84 to 168.86% for 24 hours' immersion. The results in Table 2.2 show that; overall, the sample I [P1-D (1.5) - SA] has the best water absorptive quality because it has the lowest value for both 2 hours and 24 hours' water absorption percentage.

It can be drawn out from Table 2 that the samples made with the big size of wood chips ($P_1 = 0.85$ mm) tend to absorb water faster than the samples from the smaller wood chip particle ($P_2 = 1.7$ mm) after the 2 hours' water absorption test, but the samples from P_2 absorbs more amount of water than the samples made from P_1 after 24 hours. That means the samples from P_2 are slower at absorbing water, but eventually absorbs more water than the samples from P_1 . Guler and Buyuksari (2011) reported water absorption range of 67.85 -

94.88 % of peanut hull particle boards using urea formaldehyde and cured for 24 hours.

It can also be deduced from Table 2 that the samples fabricated using the modified cassava starch (MCS) has a lower water absorption rate than the samples produced using starch alone (SA). Table 2 shows that the particle boards with $D_{1.5}$ of binder had absorbed less water, but absorbed water faster than the particle boards with $D_{2.5}$.

Table 2: Water absorption result.

Sample name	Duration	1	2	3 %	Average
R	2 hours	65.71	83.17	79.72	76.2
	24 hours	70.82	86.25	86.84	81.30
I	2 hours	32.19	37.59	28.19	32.66
	24 hours	34.35	38.29	28.87	33.84
D	2 hours	82.18	93.85	102.50	92.84
	24 hours	87.28	95.85	118.50	100.54
W	2 hours	108.72	100.21	120.76	109.90
	24 hours	110.18	106.93	128.63	115.25
A	2 hours	43.90	38.74	32.21	38.28
	24 hours	55.82	54.00	48.96	52.93
N	2 hours	85.80	91.13%	80.04%	85.66%
	24 hours	110.18	106.93	95.06	104.06
G	2 hours	55.21	63.12	52.11	56.81
	24 hours	78.39	88.45	79.55	82.13
B	2 hours	139.82	132.11	150.30	140.74
	24 hours	173.58	169.79	163.20	168.86

The less value of water absorption for the samples produced with modified cassava starch indicates that the Glutaraldehyde treatment helped to reduce the water absorption of the particle boards. The water absorption data was subjected to one-way single factor analysis of variance and the result showed that water absorption after 2 and 24 hours differed significantly between the board samples with the corresponding $F_{\text{statistics}}$, F_{critical} and p-value of 63.95, 2.66 and $p < 0.01$ respectively.

Thickness Swelling

Table 3 is the result obtained from the thickness swelling test after 2 and 24 hours respectively. Generally, the thickness swelling increased with the immersion time until equilibrium conditions were reached. The thickness swelling value ranged from 1.82% to 59.37% for 2 hours' immersion and ranged from 2.61% to 67.91% for the 24 hours' immersion. Tables 1 shows that sample I [P_1 -D (1.5) - SA] has the lowest value for thickness swelling percentage and the sample with the

highest thickness swelling percentage is sample D [P_1 -D(2.5)-MCS].

The results in Table 3 show that the samples fabricated from the larger size of wood chips particle ($P_1 = 0.85$ mm) have higher values of thickness swelling at both 2 hours and 24 hours than the samples made from smaller particles ($P_2 = 1.7$ mm). This result corresponds with (Mohd *et al.*, 2013), who reported that particle size had an effect on thickness swelling of particleboard made from 1.9mm wood particles.

It could also be seen that samples produced with D_{15} dosage of binder samples swelled in thickness more than D_{15} dosage of binder samples. The result revealed that the samples produced using modified cassava starch (MCS) as binder had high thickness swelling value than the samples produced using starch alone (SA) as a binder. This is similar to the report of Amini *et al.* (2016) who reported that 2% replacement of modified starch with urea formaldehyde resin showed increment in dimensional stability, while, Guler and Buyuksari (2011) reported thickness swelling of 12.34 - 25.71 %.

Table 3: Thickness swelling

Sample name	Duration	1	2	3	Average
		(%)			
R	After 2 hours	7.67	5.20	14.1	8.99
	After 24 hours	18.53	9.96	18.18	15.56
I	After 2 hours	0.72	3.70	1.05	1.82
	After 24 hours	1.96	4.12	1.76	2.61
D	After 2 hours	57.33	60.46	60.31	59.37
	After 24 hours	64.24	71.35	68.15	67.91
W	After 2 hours	19.22	22.46	30.81	24.16
	After 24 hours	38.73	33.51	34.35	35.53
A	After 2 hours	2.62	4.05	2.34	3.00
	After 24 hours	6.09	5.40	2.91	4.8
N	After 2 hours	7.19	11.53	18.23	12.32
	After 24 hours	8.81	17.66	19.69	15.39
G	After 2 hours	15.88	4.09	20.78	13.58
	After 24 hours	17.57	24.60	27.07	23.08
B	After 2 hours	4.29	8.53	12.32	8.38
	After 24 hours	13.29	11.80	12.63	12.57

The thickness swelling data was also subjected to one-way single factor analysis of variance and the result showed that thickness swelling of board samples after 2 and 24 hours differed significantly with the corresponding $F_{\text{statistics}}$, F_{critical} and p-value of 45.47, 2.66 and $p < 0.01$ and 100.65, 2.66 and $p < 0.01$ respectively.

Flexural Tests

The mechanical properties of five specimens of each composition and the average values are presented in Table 4. The particleboards produced using modified cassava starch gave the highest value of modulus of elasticity (MOE), ranging from 5.907 to 32.320 N/mm². From the results shown in Table 3.2, MOR of the particleboards is in the range of 0.055-0.342 N/mm², indicating the highest value of 0.342 N/mm² for the sample R [P1-D (1.5)-MCS]. The MOR result also shows that P1-D (1.5) = 1.7mm size wood chips with 1.5 dosages of the binder, and P2- D (2.5) = 0.85 mm wood chips with 2.5 dosages of binder had the highest MOR. Rafael R. de Melo *et al.* (2014) also reported a similar MOE range of 5.19 to 34.27 N/mm² and MOR in the range of 0.09- 0.85 N/mm² using modified cassava starch for the production of particleboards from *Ailanthus* wood.

The two combinations above are the particleboards that produced higher values of MOE and MOR, this indicates that when using bigger wood chips particleboard, it is better to

use less dosage of the binder, then while using smaller particles for production, it is advisable to use more dosage of the binder.

Table 4: Mechanical Properties of Boards.

Sample name	Test	1	2	3	Average
		MPa			
R	MOE	25.59	10.99	25.29	20.62
	MOR	0.38	0.32	0.33	0.34
I	MOE	11.16	12.03	12.30	11.83
	MOR	0.24	0.24	0.28	0.25
D	MOE	10.12	4.34	3.26	5.91
	MOR	0.21	0.12	0.08	0.14
W	MOE	1.78	2.13	2.28	2.06
	MOR	0.10	0.11	0.12	0.11
A	MOE	8.37	17.04	31.16	18.86
	MOR	0.08	0.244	0.274	0.20
N	MOE	1.77	1.85	0.761	1.46
	MOR	0.06	0.06	0.05	0.06
G	MOE	29.95	23.75	43.26	32.32
	MOR	0.32	0.35	0.29	0.32
B	MOE	2.38	4.93	3.31	3.54
	MOR	0.08	0.14	0.4	0.12

It can be deduced from Table 5 that all particleboards produced with the modified cassava starch have much higher MOE and MOR than the boards produced with starch alone as a binder. This shows that the Glutaraldehyde modification had a positive effect on the MOR and MOE of the particleboard. The higher mechanical properties of the samples due to chemical modification was an indication of improved interaction and stress transfer between the individual particles of the board (Zhang *et al.*, 2014; Elbadawi *et al.*, 2016). Shown in Table 5 is the result obtained from the analysis of variance performed on the MOE and MOR data from samples of each formulation. The ANOVA shows that MOE and MOR varied significantly between samples.

Table 5: MOE and MOR Analysis of Variance.

	F	P-value	F crit
MOE	9.21	0.00	2.66
MOR	5.15	0.00	2.66

$df_1 = 7$ $df_2 = 16$

The particleboard formulation G [P2-D (2.5)-MCS] recorded average MOR and MOE values of to 0.32 N/mm² and 32.32 N/mm² respectively, the highest values recorded in comparison to other formulations. Raju *et al.* (2012) reported a maximum MOR and MOE of 40.57 MPa and 8.20 GPa of particles boards manufactured using modified starch, while Guler and Buyuksari (2011) reported that the MOR and MOE of boards manufactured

using urea formaldehyde were in the range of 2.90 - 12.14 Mpa and 20.35 – 57.18 Mpa respectively.

SEM Analysis

The results from the scanning electron microscope are mainly in the form of visual images, supported by quantitative analysis of data on micro-checks and voids.

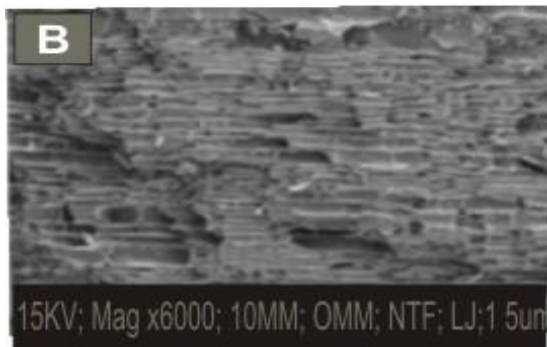


Figure 2: SEM images of sample B at magnification x 6000

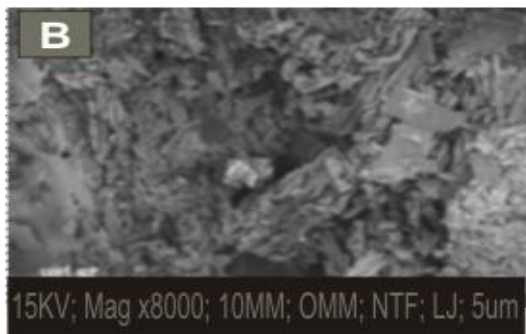


Figure 3: SEM images of sample B at magnification x 8000

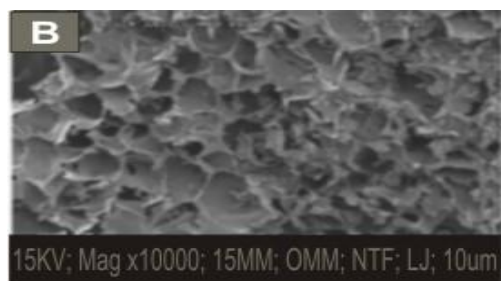


Figure 4: SEM images of sample B at magnification x 1000

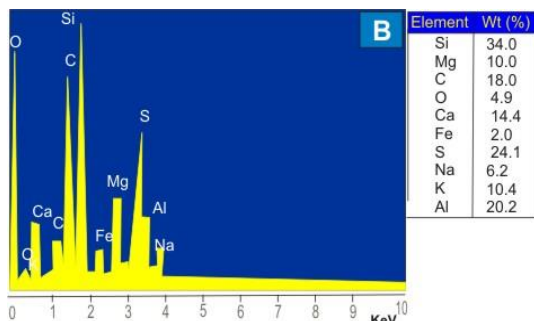


Figure 5: The EDS analysis result of sample B

From the SEM images above, well-defined plate-like, near rectangular crystal formations are observed on sample B at x 6000 magnification. Also, the crystal formations in sample B at x 10000 magnification are circular

in appearance and closely packed together. The developed and well-defined crystals formations show that there is a successful high strength bond formation between the modified cassava starch and wood chips at 1.5 dosages of the binder.

The EDS analysis result for sample B shows that the major elements in the composition are Calcium, Aluminum, Carbon, Sulphur, Silicon and Potassium, while the minor components are Magnesium, Iron, Oxygen, and Sodium.

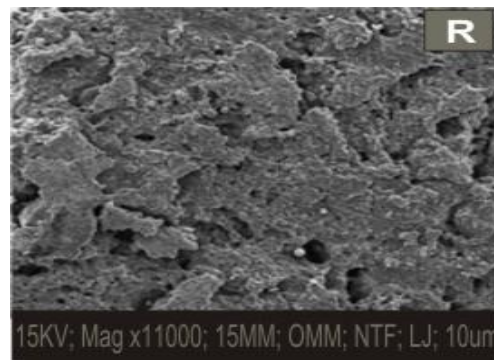


Figure 7: SEM images of sample R at magnification x 12000

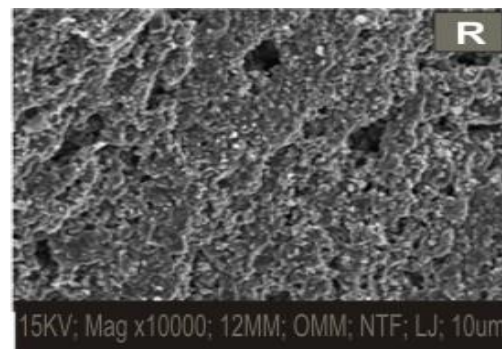


Figure 8: SEM images of sample R at magnification x 11000

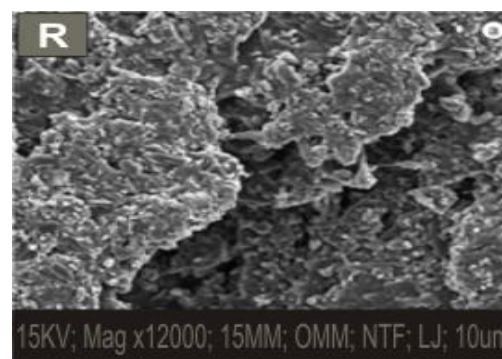


Figure 9: The EDS analysis result of sample R

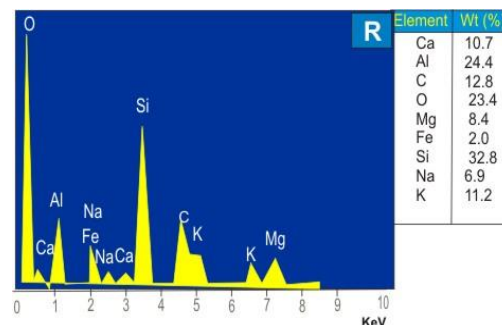


Figure 10: SEM images of sample R at magnification x 10000

The SEM images for sample R at magnification sizes x 10000, x 11000 and 12000 reveals that there are small discontinuities and a non-uniform distribution of particles and the binders. The particles phase is shown as a white phase, while the binder phase is the darker phase. The wood chip particles are embedded within the amorphous matrix composed of randomly distributed in the matrix planar boundaries. The surface of the wood chip particles is rough indicating that the compatibility between particles and the binders was not as good as the bond in sample B, but it can be seen that the wood chip particles were not detached from the binder surface.

The EDS analysis result for sample R shows that the major elements in the composition are Calcium, Aluminum, Carbon, Oxygen, Silicon and Potassium, while the minor components are Magnesium, Iron, and Sodium. Though both EDS analysis of the two samples is similar, however, sample B has Sulphur and Oxygen.

Conclusions

The following can be deduced from the research:

1. The production of particleboard from the materials is technically feasible
2. The modification of cassava starch with Glutaraldehyde improved the mechanical properties of the particleboard and the water absorption, but it increased the thickness swelling of the samples.
3. The cassava starch and wood chips can be considered as an alternative for raw material in the manufacture of particleboard used in indoor environment due to moderate mechanical properties, low water absorption and no health hazard (no formaldehyde emission).

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