The Recycling of Sawdust Waste into Particleboard Using Starch-Based Modified Adhesive

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Abstract: *The challenges associated with the management of wastes from the cassava processing and timber industries necessitated an investigation into the possibility of implementing recycling approach to produced particle board from these wastes. Particleboards were produced from wood saw dust using various compositions of modified starch adhesives. The product obtained were evaluated for density, moisture content, hardness, flexural strength, water absorption and thickness swelling. The results obtained indicated that the density ranged from 753 to 798 kg/m^3, moisture content ranged from 14.87 to 16.67 %, hardness ranged from 9.02 to 9.31 N/nm^2, flexural strength ranged from 1.31 to 1.45 MPa, water absorption capacity at 24 h ranged from 1.06 to 9.31 %, thickness swelling ranged from 4.55 to 4.78%. The products were in conformity with IS 3087 (2005) and ANSI A 208.1 (1993) standards and could go for medium density particleboard.*

Key Words: *Resource recycling, particle board, cassava processing waste, wood saw dust*.

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1.0 Introduction

Waste generation is one of the major threats to the environment. Industrial development, urbanization and agricultural practices have been highlighted as the major source of wastes in our environment (Young *et al*.,2010). However, little attention is directed to the wood industries, which has great potential to generate toxic waste into the land, water and air (Harshavardhan and Muruganandam (2017). Combustion of wood saw dust can generate air pollutants such as CO_2, CH_4, NO_x, SO_x and other toxic gases (Gimbutaite and Veneckus 2008; IARC, 2006). Wood rich in heavy metals can pollute the soil when they decay or be leached to surrounding water bodies (Sardar *et al.,* 2013). Approaches to wood management vary but one of the most beneficial approach is resource recycling which defines turning wood to useful product (Harshavardhan and Muruganandam (2017).

One of the most successful approaches to the management of wood saw dust is the production of particle boards from it. Particle board is a composite wood product of sawdust (and agricultural waste) blended with synthetic resins or organic adhesives and extruded into solid form (Wang and Sun, 2002). Formaldehyde resins such as amino formaldehyde, urea melamine and phenol formaldehyde resins have been used for decades in the production of particleboard but due to its effect on end users, have now been banned (IARC, 2006). However, due to the formation of formaldehyde, carbon monoxide and hydrogen cyanide which are carcinogenic, recent research interest is directed to green synthetic routes that will eliminate the generation of toxic materials. The use of starch of plant origin has given hope for ecofriendly production of particle board (Kennedy, 1989; Xu *et al*., 2014).

Modified starch adhesives are now used for adhesion of materials because they are safe, non-toxic, grossly underutilized, renewable and cheap and exhibit the required characteristics of tack, resistance to moisture, binding strength and durability.

Rowel *et al*. (2000), reported the use of crop wastes to produced particleboard, which accounted for recycling process. Scantolino, *et al*. (2013) produced particleboard using maize cob and obtained commendable mechanical properties. Ndubaba, (2013) and Bamisaye, (2017), obtained their particleboard from rice husks and from combination of rice husk and wood saw dust (Ndubaba, 2013). Akinyemi *et al*. (2019) produced particleboards from wood saw dust using native cassava modified with 25 % glutaraldehyde solution. Observed density of the produced boards was found to range from 0.21 to 0.54 g/cm^3, Thickness swelling after 2 to 24hrs immersion, ranged from 1.8 to 67.9 % while water absorption ranged from 32.7 to 168.9%. Peak values of modulus of elasticity and modulus of rupture were 3232 and 35.7 Nnm^2. Observation of the surface morphology of the board through scanning electron microscope indicated well dispersed granules on the surface while FTIR spectrum revealed the occurrence of aldehyde and ester. Studies conducted by Abu-Zarifa *et al*. (2018) on the production of particle boards from saw dust and agricultural materials revealed maximum modulus of elasticity (MOE) value (2160.78 MPa), at wheat 75%, maximum modulus of rapture (MOR) value (11.07 MPa) at sawdust 100%, and the maximum value of max-stress (7.8 MPa) at banana 75%, the range of water absorption values was between (8.19%, 19.3%). They concluded that their results were better than commercial types (MDF, Fiber and Press wood), which reach to 103% in MDF. Kariuki *et al.* (2019) produced particle board using lignocellulose materials (sugarcane bagasse, maize stock, and rice husks) and cassava starch mixed with borax as binder. The resultant particleboards had mean densities ranging from 0.604 to 0.611 g/cm^3. The modulus of elasticity ranged from 2364.2 N/mm^2 to 3329.93 N/mm^2, modulus of rupture ranged from 13.55 N/mm^2 to 14.83 N/mm^2, and internal bonding ranged from 1.613 N/mm^2 to 2.370 N/mm^2. The performance of the board was dependent on the lignocellulose material used. Fourier transform infrared spectroscopy analysis showed that main chemical bonding in the particleboard resulted from esterification of –COOH from lignocellulose and OH- from starch. The particleboards formulated were found to be of low-density-fibre standard used in a similar manner to the conventional low-density particleboards.

Waste management process becomes more profitable when it involves resource recovery, reuse and recycling (Lacovidou *et al.,* 2017). Wood saw dust is excessive available in Nigeria especially in the Southern Part of the country. Their disposal has generated several environmental concerns (Jeong, 2011). Also, cassava processing mills have found difficulty in managing the effluent generated from their sources (Cumbana *et al.,* 2007). Therefore, attempt to utilize these wastes whose management constitute environmental nuisance can impart positively on ideal waste management principles. Consequently, in this study, attempt is made to produce particle board from wood saw dust and effluent from cassava processing mill.

2.0 Material and methods

2.1 Sample collection

The starch effluents were obtained from a cassava mills in Abiakpo Ikot Essien, in Ikot Ekpene Local Area of Akwa Ibom State, Nigeria. The collected samples were reprocessed into pure fine product through washing and re-filtration several times with clean water. The filtrate was allowed to stand for 2hrs for settling of the residues. The supernatant was poured off and the residue dried and stored for further use.

2.1.1 Sawdust collection

The sawdust particles were collected from Utu Edem Usung timber market dump sites and transported to the laboratory for processing and stored for further use.

2.2 Composition of the modified starch

Formula 1: The modified starch was formulated in the laboratory using Starch 100.0g. sodium hydroxide 1.405 M, polyvinyl acetate 63.59gms, sodium trioxocarbonate (IV) 0.472 M, carboxyl methyl cellulose 3%, disodium tetraborate 3%, water 200 ml and sawdust 300.0g

Formula 2: Starch 200.0g, sodium hydroxide 1.405 M, polyvinyl acetate 50.0g, sodium trioxocarbonate (IV) 0.472 M, carboxyl methyl cellulose 3%, disodium tetraborate 3%, sodium benzoate 3% water 200ml and saw dust 300.0g.

2.3 Particleboard production

Sample A was produced from formula 1 while sample B was produced from formula 2. The modified starch and the sawdust were mixed and blended in the laboratory using different formulations. The blended mix was placed in a thick steel mold with the top covered with a smooth surface metal and cooled pressed by placing a heavy weight on it for a period of three hours. The product was hydraulic pressed at a temperature of 100^{o}C to activate the adhesive into a solid product. (European standard: EN 312, 2013).

The physico-mechanical properties of the products were determined. Each piece of the particleboard was cut into four pieces to analyze for the following properties, density, hardness, flexural strength, moisture content, water absorption and thickness swelling using standard procedures.

2.4 Testing methods

The following methods were employed for density, hardness, water absorption, thickness swelling, flexural strength based on Jove Science 2020, ASTM E384-17, ASTM C1161-0 2c(2018)

2.4.1 Determination of the density of particleboard

The density of the particleboard was determined according to Jove (2020) using the liquid displacement method. Density (g/cm^3) was calculated using mass/volume. The mass of the sample was weighed using a digital analytical Metlar balance (model M311L) and a 100ml volumetric cylinder used for the volume.

2.42 Determination of moisture content

The moisture content was estimated using the following equation,

$$Mositure\ content\ (\%) = \frac{W_b - W_a}{W_a} \times \frac{100}{1} \quad (1)$$

Where wb = weight of sample before drying and wa = weight of oven dried sample.

2.4.3 Determination of Water absorption and Thickness swelling

Water absorption and thickness swelling were determined according to ASTM D -570-98 (2018). Some blocks of the sample were cut and heated in an oven at100^{O}C for 30mins to remove any trace of water and stored in desiccator for 2hrs. The initial weights and their corresponding thicknesses were measured with digital balance and vernier caliper to the nearest 10^{-3}g and 10^{-3}mm respectively. All the samples were immersed in distilled water for 2hrs, 4hrs 12hrs and 24hrs at room temperature (22±3^{O}C) and readings taken. Water absorption and thickness swelling were estimated using the following relationship,

$$Water\ absorption\ (\%) = \frac{M_f - M_i}{M_i} \times \frac{100}{1} \quad (2)$$

Mi is the oven dried mass (gm) of specimen before immersion in distilled water and M_f is the final mass (gm) of specimen after immersion in water.

$$Thickness\ Swelling\ (\%) = \frac{h_f - h_i}{h_i} \times \frac{100}{1} \quad (3)$$

where TS% = Percentage of thickness swelling, is the initial thickness (mm) of the sample after being oven dried and h_f is the final thickness of specimen after immersion in water.

2.4.4 Determination of hardness

Hardness was determination according to ASTM E384-17 (2017). Hardness is a measure of resistance of a material to the penetration of an indenter under an applied force Kevin, Ochanya, Olukemi, Bwanhot and Uche (2018). It was determined using the relationship:

$$H_v = 1.854\left(\frac{F}{D^2}\right) \quad (4)$$

where F is the applied load, D^2 is the area of indentation (mm^2) and Hv is the Vickers Number.

2.4.5 Determination of flexural strength

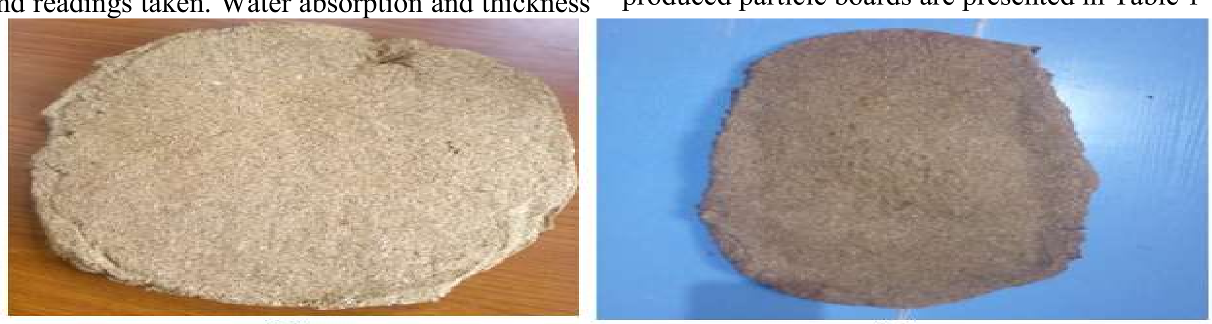
Flexural strength was determined based on Ashby_mech_design-1 method (2011). Each sample was cut into various sizes. Centre point loading was applied until fracture occurred and was calculated mathematically as;

$$\sigma = \frac{3FL}{2bd^2} \quad (5)$$

Sigma σ is the flexural strength N/mm^2, F is the force applied (N); l, b, d are the length, breadth and depth or thickness (millimeters) respectively.

3.0 Results and Discussions

Pictures of particle boards produced from formula 1 and 2 (described in section 2.2) are shown in Fig. 1a and 1b respectively. Functional properties of the produced particle boards are presented in Table 1



(a) (b)

Fig. 1: Photographs of particle boards produced from formula 1(1a) and formula 2 1(b)

Table: 1: Properties of the produced particle boards

S/No	Sample type	Density Kg/m^3	Moisture content %	Hardness N/mm^2	Flexural strength MPa
1	Sample A	798	16.67	9.31	1.45
2	Sample B	753	14.87	9.02	1.51

The observed density of both particle board samples are within the recommended IS3087 (2005) range of 500 -900Kg/m^3. There are also in strong agreement with density values of 719 and 736 kg/m^3 reported by Iwakiri *et al.*, (2014) for particle board produced from sequoia sempervirens and *Pinus taeda* wood. Wood density is an important factor in the determination of the quality of particleboard as it dictates the physical and mechanical properties of particleboard Kelvin *et al*., (2018). According to IS 3087 (2005) recommended range for the moisture content of standard particle board is 5 to 15%. However, sample A showed a value of 16.67% and sample B, 14.87%. The difference in the value of sample A from the standard could be attributed to different proportion of the constituents of the modified starch adhesive while sample B was in conformity with the standard. Harshavardhan and Muruganandam (2017) reported moisture content of 3.97% for particle board produced from urea formaldehyde resin and sawdust which showed that the samples with the modified starch adhesives have improved quality. Particleboard with moisture content outside the expected range often experience irregularity in linear dimension and thickness. Lower moisture content could cause an irregular bending of the particleboard while a higher one would affect the strength of the particleboard. Hence sample B is expected to be of an improved quality (Harshavard and Muruganandam, 2017).

Hardness of the produced particle boards were 9.31 and 9.02 N/mm^2 respectively. The hardness of particleboard and fireboard refers to the ability of the board surface to resist residual deformation due to static or dynamic load of other objects. Hardness of particleboard is dependent on the surface density because, the higher the density the harder the particleboard. However, this is also related to moisture content and the composition and processing method employed in its production.

Flexural strength is a factor of the product suitability, longevity and applicability of the particular product and end user's safety (Laemlaksakul, 2010). Flexural strength of the samples ranged from 1.45 to 1.51 MPa for sample A and sample B respectively. These values are lower than the minimum expected for IS 3087 (2005) recommended range, that is, 9 to 11 MPa. However, Harshavard and Muruganandam (2017) reported 6.470 MPa while Iwakiri *et al*. (2014) 12.78 and 18.96 MPa for particle boards produced from *Sequoia sempervirens* and *Pinus taeda* wood saw dust respectively. Therefore, the observed values in the present study are not unusually out of range and may not contribute significantly to the performance of the produced board depending on expected applications. Mean water absorption capacity of the produced particles boards displayed some similarity in trend as shown in Fig. 2, which present plots of water absorption capacity (%) against period of contact (hour).

The water absorption of sample A decreased from 84.92 to 9.14% while that of sample B, decreased from 183.5 to 1.06%. The observed range are in accord with IS3087 (2005) recommendation of 40% as the maximum water absorption capacity after 24 hours. Therefore, the values agree with the standard. However, the variation in water absorption between the two boards could be due to the different properties exhibited by the modified starch. According to Iwakiri *et al*., (2014), water absorption for particleboard made with Sequoia *sempervirens* and *Pinus taeda* wood dusts using urea formaldehyde resin which ranged from 26.3 to 45.4% also led to enhanced mechanical performance.

Fig. 3 show the plots for the variation of thickness swelling with period of contact. The two plots seem to be parallel to each other indicating that the swelling mechanism is the same for both irrespective of the slight difference in composition. The plots generally depicted a decreased in the absorption of water to a saturated point up to 24hrs.

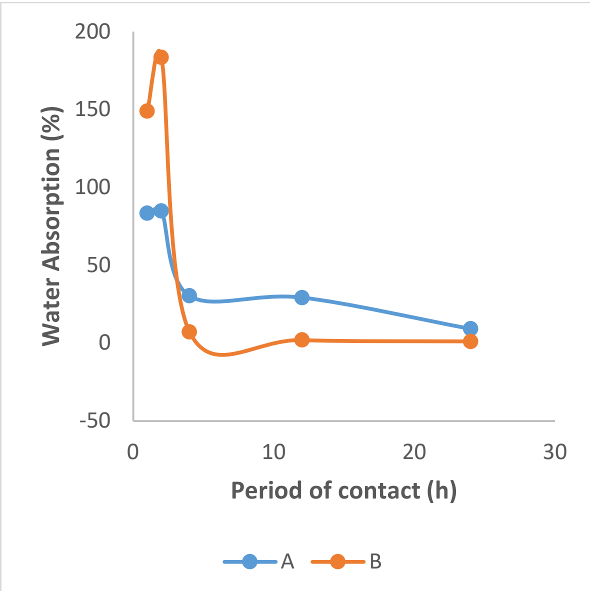


Fig.2: Water absorption capacity% against period of contact for the produced particleboard

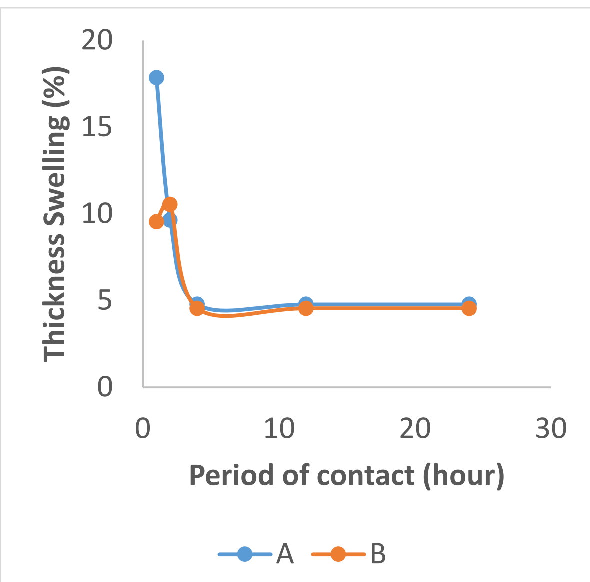


Fig.3: Variation of thickness swelling with period of contact for the produced particle boards

Thickness swelling of the samples were constant after a period of 2hrs which showed the saturation of the samples having absorbed much moisture. Thickness swelling is a property that is used to ascertain the stability performance of the sample. Mean thickness swelling for sample A was 4.78% while that of sample B was 4.55%. Iwakiri *et al*., (2014) reported that particleboard produced from Sequoia *sempervirens* and Pinus *taeda* with urea formaldehyde resin had thickness swelling that raged from 8.3 to 22.2% with the later slightly above 12%, which is the limit recommended by IS3087 (2005) standard (Appendix 1). However, Harshavard and Muruganandam (2017) reported 2.6% for particleboard produced from sawdust and urea formaldehyde resin.

4.0 Conclusion

Based on the result obtained, the following conclusions were deduced,

(i) Samples A and B showed some properties similar to earlier works and standards.
(ii) As a new product thickness swelling and moisture content differed with the IS 3087 (2005) standards due to different compositions of the used adhesives.
(iii) The properties of the particleboard are consequences of the percentage composition of the components which are dependent on the adhesive, filler ratio.
(iv) From the compared result it showed that increased in the proportion of the components would improve the desired properties.
(v) The sawdust waste if harnessed into useful product could reduce environmental pollution.
(vi) The products could be used as medium density particleboard

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Conflict of Interest

The authors declare no conflict of interest

Appendix 1: IS 3087 Standard for Physical and Mechanical properties of particleboard

Properties	**Sample A**	**Sample B**	****Culled result of sawdust particle board**	**IS 3087 (2005) Standard values**
Density (Kg/mm^3)	798	753	921	500-900
Water absorption % 24hrs	9.14*	1.06*	31.3	Maximum 40
Thickness swelling % 24hrs	4.78*	4.55*	2.6	Maximum 12%
Hardness N/mm^2	9.31	9.02	-	-
Moisture content %	16.67	14.87	3,97	5-15%
Flexural strength MPa	1.45	1.51	6.47	9-11

Source: Harshavardhan and Muruganandam (2017).