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PROPERTIES OF FIBREBOARDS MADE FROM OIL PALM (*ELAEIS GUINEENSIS*) STEM AND/OR MIXED TROPICAL HARDWOOD SAWMILL RESIDUES

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ONUORAH, E. O. 2005. Properties of fiberboards made from oil palm (*Elaeis guineensis*) and/or mixed tropical hardwood sawmill residues. The potentials of oil palm (*Elaeis guineensis*) stem and / or mixed tropical hardwood sawmill residues for making dry-formed resin-bonded medium density fibreboard (MDF) and / or wet-formed hardboard were investigated. Chips/fibrous strands of 15 to 25 mm length by 4 to 7 mm thick with variable widths of < 15 mm were digested into pulp using 1.5% NaOH at material:liquor ratio of 1:3.5. The cook lasted 90 min at 25 °C, pH 10.5 and 0.45 MPa. Pulp yields were high (86–88%) and screen rejects were at acceptable levels (1.76–4.11%). Boards were made either as 9.53 mm thick MDF (SG = 0.7, resin content = 7%) or 3.175 mm thick hardboard [SG = 0.8 of either two smooth surfaces (S2S) or screen meshed back (S1S)]. Boards were sampled and conditioned at 20 ± 2 °C and 65 ± 2% relative humidity, and tested in accordance with ASTM D 1037–90. Ten replicates were used for each test for each product. MDF made from tropical hardwood sawmill residues had higher modulus of rupture (MOR) than those from oil palm or mixed furnish. S2S hardboards had higher MOR and modulus of elasticity (MOE) than S1S. S1S hardboards had higher internal bond than S2S hardboards. The MDF and different hardboards had acceptable properties.

Key words: Fibre dimensions – medium density – fibreboard – urea formaldehyde – wet-formed hardboard

ONUORAH, E. O. 2005. Ciri-ciri papan gentian yang dibuat daripada batang kelapa sawit (*Elaeis guineensis*) dan/atau sisa kilang papan daripada campuran kayu keras tropika. Kemampuan batang kepala sawit (*Elaeis guineensis*) dan/atau sisa kilang papan daripada campuran kayu keras tropika menghasilkan papan gentian berketumpatan sederhana (MDF) secara pembentukan kering dengan ikatan resin dan/atau papan gentian keras secara pembentukan basah dikaji. Serpai/lembar bergentian berukuran 15 mm–25 mm panjang, 4 mm–7 mm tebal dengan pelbagai lebar yang tidak melebihi 15 mm dihadamkan untuk dijadikan pulpa menggunakan 1.5% NaOH dengan nisbah pepejal:cecair sebanyak 1:3.5. Campuran dimasak selama 90 min pada 25 °C, pH 10.5 dan 0.45 MPa. Hasil pulpa tinggi (86–88%) dan bahan ditolak selepas saringan adalah pada tahap yang boleh diterima (1.76–4.11%). Papan dijadikan MDF setebal 9.53 mm (SG = 0.7, kandungan resin = 7% atau papan keras setebal 3.175 mm [SG = 0.8 sama ada mempunyai dua permukaan licin (S2S) atau permukaan belakang berjaringan skrin (S1S)]. Papan disampel dan disimpan dalam keadaan 20 ± 2 °C dan 65 ± 2% kelembapan relatif. Papan kemudiannya diuji berdasarkan piawai ASTM D1037–90. Sebanyak 10 replika digunakan untuk setiap ujian bagi setiap papan. MDF daripada

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sisa kilang papan yang mengandungi kayu keras tropika mempunyai modulus kepecahan (MOR) yang lebih tinggi daripada papan daripada kelapa sawit atau papan daripada bahan bercampur. Papan keras S2S mempunyai MOR dan modulus kekenyalan (MOE) yang lebih tinggi daripada papan S1S. Papan keras S1S mempunyai ikatan dalam yang lebih tinggi daripada papan keras S2S. MDF dan papan keras berlainan memiliki ciri papan yang memuaskan.

Introduction

Until the 1970s, the Nigerian economy was agricultural driven. Sales from oil palm produce (palm oil and palm kernel), cocoa, groundnuts, cotton as well as hides and skin contributed to the national economy. The regional government of the East established millions and millions of hectares of oil palm plantations and some of the downstream economic sectors. Nigeria was then the foremost world exporter of palm oil and palm kernel (Udoh 1970).

The oil boom (otherwise referred to as rise in economic fortunes of the nation as a result of rise in crude petroleum prices) caused a decline in investment in agriculture. This is because the government had inadvertently encouraged mass migration of workers to urban centres. Distributive and service trades were encouraged instead of agricultural and other productive investments. Today, Nigeria is left with several billion cubic metres of oil palm fibrous stem in overgrown and poorly managed plantations that are increasingly becoming difficult to harvest. Fibrous oil palm stem remains a national enigma.

Concomitant to the above scenario is the present high level of inefficiency in the nation's wood-based industrial sector (Badejo & Giwa 1985, World Bank 1992). This is because several million tones of wood residues generated by the sector remains substantially unutilized. Many experts in wood utilization had recommended the use of integrated wood complexes as a means of wood waste reduction and as a sustainable management policy (Lucas 1977, Olufemi 1988, Iloabachie 1989, Lebel *et al.* 1994). There is, therefore, an urgent need to expand the national industrial fibre base. The use of agricultural residue to augment shortfall in forest timber supply and to enhance sustainable industrial fibre management is on the increase (Nnabuife 1987, Wang 1998, Chen 2000, Zeng 2000, Onuorah & Nnabuife 2001).

The objectives of this study were to evaluate the potentials of oil palm (*Elaeis guineensis*) fibrous stem and / or mixed tropical hardwood sawmill residues as raw-material for dry-formed medium density fiberboard and / or wet-formed hardboard.

Materials and methods

Materials

Elaeis guineensis (oil palm) stems were cut from a 36-year-old plantation located at Igbariam farm settlement (6° 20' N latitude and 6° 43' E longitude) in Anambra East local government of Anambra State, Nigeria. Each stem, as felled, was cut at the point where the palm fronds were still attached to the stem. The clear bole was subsequently cut into billets of 0.46 m length. Each billet was kept in the open in the laboratory for air seasoning for three months. Each air-seasoned billet was split into two. One half was used for chemical analysis while the other was manually and mechanically reduced to chips in a revolving disk chipper.

The sawmill residues used for this study were obtained from a private tropical hardwood sawmill located in Onitsha (6° 6'' N latitude and 6° 42'' E longitude), South-East Zone, Nigeria. The sawmill processes tropical hardwoods cut from rain forest and savanna vegetation belts. About 25 different species were reported to be processed regularly but records of their frequency were not kept. The sawmill residues, received from the sawmill, consisted of saw dust, off cuts, slabs and edgings. They were spread in the workshop for three months for air seasoning. At the end of this period, large sizes were reduced to chips in a disk chipper.

The chipped materials (either fibrous strands of oil palm stem or mixed tropical hardwood sawmill residues) were screened in an improvised laboratory vibrating screen. Chips of average length ranging from 15–25 mm and thickness of 4–7 mm were used for pulping.

A liquid urea formaldehyde (UF) resin was used as a binder in the dry process of medium density fiberboard manufacture. This resin has, according to manufacturer's specifications, 65% solid content. All other chemicals used in this study were of analytical grades.

Methodology

Wet chemical analysis

The wet chemical analyses of chips / fibrous strands of either oil palm stems or mixed tropical hardwood sawmill residues were conducted in accordance with the provisions of the Standard Test Methods of the Technical Association of the Pulp and Paper Industry (TAPPI 1998). The chips were dried in an oven at 105 ± 2 °C for 24 hours, reduced to powder in a Wiley mill and finally screened through a 60 BSS mesh. Milled powder, which passed through 60 BSS mesh and retained on 80 were chosen and then used for wet chemical analysis.

Pulping

The pulping parameters are as stated in Table 1. At the end of each pulping period, the digested chips / fibrous strands were washed thoroughly in water to remove any residue chemical and then refined in a Sprout Waldron refiner at 10% consistency (Kumar *et al.* 1989). About a third of the refined fibres were later spread on screens for air seasoning and were subsequently used for dry-formed medium density fibreboard.

Determination of fibre dimensions

Representative pulp samples were taken immediately after pulping and used for determination of fibre dimensions. These groups of softened chips/fibre bundles were exposed to further defibrillation by subjecting the pulp suspensions, in the presence of glass beads, to vigorous agitation. Representative fibre samples were then taken and mounted on slides and viewed at 10× magnification using a microscope. The fibre dimensions (length and width) were measured 'wet' with the aid of stage and ocular micrometer scales (Akpabio 1989).

Table 1 Pulping conditions for cold soda digestion of *Elaeis guineensis* stem and mixed tropical hardwood sawmill residues and the resultant unbleached pulp yields and screen rejects

1 Pulping parameters

Chip dimension: 15 to 25 mm length by 4 to 7 mm thick by variable width not exceeding 15 mm
NaOH = 1.5%
Material:liquor ratio = 1:3.5
pH = 10.5
Temperature = 25 °C
Time to temperature = 30 min
Time at temperature = 60 min
Pressure = 0.45 MPa

2 Unbleached pulp yield (%)

Exclusively oil palm stem furnished (EOPF) = 86.00
Exclusively of mixed tropical hardwood sawmill residues (EMHR) = 88.00
Randomly mixed furnish comprising* 30% mixed tropical hardwood sawmill residues (EMHR) and 70% of oil palm stem furnish (HPF) = 86.50

3 Screen rejects (% for unbleached pulp) **

EOPF = 1.76
EMHR = 4.11
HPF = 2.21

* mix ratio on oven dry wt / wt basis
** pulp were screened through a vibrating screen with 0.30 mm slots

A total of 130 representative fibre samples each were sampled from *E. guineensis* fibrous stem and mixed tropical hardwood sawmill residue generated fibre/pulp. The mean fibre dimensions, standard deviation and percentage range distribution were determined.

Board manufacture

Pulp derived from the above three types of furnish were used for the manufacture of dry-formed medium density fibreboard or wet-formed hardboard. The latter were made as wet-formed hardboard with two smooth surfaces (S2S) or one smooth surface (S1S or screen-back board). The board pressing parameters are shown in Table 2. The board pressing conditions were based on results obtained from preliminary trials.

A total of 45 boards were made (3 furnish types by 3 board types by 5 replicates for each type of board). At the end of the pressing cycle, manufactured boards were stacked and covered with tarpaulin. The latter action was to provide conditions for a more gradual cooling of the manufactured boards. After two weeks, the cover was removed.

Table 2 Board pressing condition

Parameter	Type of board		
	Medium density dry-formed fibreboard *	Wet-formed hardboard (S1S)	Wet-formed hardboard (S2S)
Board length width (mm)	430.82 × 430.82	431.052 × 431.052	431.052 × 431.052
Board thickness (mm)	9.53	3.175	3.175
Target specific gravity	0.70	0.80	0.80
Resin content (%)	7.00	–	–
Pressing temperature (°C)	205	205	230
Pressure (MPa)	7.00	7.50	8.00
Duration of pressing (min)	5	6	6
Average mat moisture before pressing (%)	15	35	30
No. of board per production mix	5	5	5

S1S = Screen-back board with only the reverse surface smooth
S2S = Board with both surfaces smooth
* = Urea formaldehyde resin used as binder (quantity based on oven dry wt of fibres and solid resin content).

Sampling and testing

Specimen preparation

The boards were tested in accordance with the provisions of the American Society for Testing of Materials, ASTM D 1037–90 (ASTM 1990). All test specimens were conditioned at 65 ± 2% relative humidity and 20 ± 2 °C for two weeks before testing.

Board testing

Physical properties

Water soak tests were done using standard specimens (ASTM D 1037–90). Using sensitive laboratory weighing balance (accurate to ± 0.001 g), specimen weights were obtained and recorded. After weighing, each specimen was quickly wrapped in aluminum foil. Earlier, each specimen was marked at three equidistant points along the length and plane of the board. The thickness of board at each of these points was measured and recorded. Later, specimens were unwrapped and horizontally submerged in distilled water at 24 ± 2 °C for 24 hours. A total of 10 replicate specimens were used for each board type (boards produced under same production parameter) for the water soak and thickness swelling tests. At the end of each test period, specimens were quickly removed from water, wiped with paper towel, rewrapped in thin aluminum foil and subsequently reweighed. Percentage water absorption was based on the relative gain in weight over the original weight at inception of the test. Thickness swelling was based on the percentage difference between the weighted average measurements taken at the three equidistant points. The gain in dimensions (based on the weighted average) were reported as percentage thickness swelling relative to initial thickness.

Static bendings

Static bending test specimens were 7.62 × 35.56 cm × board thickness (9.53 mm for MDF and 3.175 mm for hardboards). Loads were applied at a head speed of 6 mm min^{-1} in Universal Testing Machine (Tinus Oslen 54, 432 kg load). The effective span was 30.48 cm. Two specimens were used per board. This gave a total of 10 replicates per board type (boards of same production parameter). In the case of hardboards with screen meshed back (S1S), half the test samples were tested with the screen meshed face in compression side. Replicates were selected randomly. Data collected were modulus of rupture (MOR) and modulus of elasticity (MOE).

Internal bond strength

Internal bond (IB) tests were performed on 5.08 × 5.08 cm × board thickness. Load was applied at a rate of 2.032 mm / mm of thickness per min. Ten replicates were tested for each board type.

Results and discussion

Table 1 presents the unbleached pulp yields and screened pulp rejects for the different types of furnish used. The pulp yields were 86.0, 88.0 and 86.5% for oil palm stem, mixed tropical hardwood sawmill residues and mixed furnish consisting of 30% mixed tropical hardwood sawmill residues and 70% oil palm stem fibrous strands (percentages are based on oven dry wt / wt basis of the chips before pulping) respectively. These yields were within the acceptable range (Kumar *et al.* 1989) for semi-chemical pulping processes. The screen rejects recorded were 1.76, 4.11 and 2.21% respectively for pulps produced from oil palm stem, mixed tropical hardwood sawmill residues and mixed cook. Although these low screen reject levels were recorded at a laboratory scale experiment they are indicative of the amenability of the different types of raw material / furnish to cold soda semi-chemical cooks.

Table 3 presents the results of chemical analysis of an oil palm stem and that of a typical mixed tropical hardwood sawmill residues. The analysis revealed acceptable hollocellulose content (73.79% for oil palm stem and 81% for mixed tropical hardwood sawmill residues). These results compared favourably with those of other species, which had been used for the production of high yield pulps (Kumar *et al.* 1989, Tsoumis 1991, Zeng 2000). With mild delignification methods, the pulp yield from both sources will be high enough for economic production of pulp.

Table 3 Chemical characteristics of *Elaeis guineensis* stem and mixed tropical hardwood sawmill residue

Test	Results on oven dry weight basis (%)	
	Oil palm stem	Mixed tropical hardwood sawmill residue
Solubility in		
Cold water	2.28	3.18
Hot water	4.39	5.01
1.0% NaOH	23.88	26.25
Alcohol–benzene (1:2)	3.38	4.50
Ash	3.42	3.60
Silica	1.01	2.60
Pentosan	22.10	27.00
Cellulose	51.69	54.00
Lignin	23.74	22.13

Values are weighted averages from five determinations.

Table 4 presents the fibre length and width distribution, mean fibre length and width, standard deviation and fibre length:width ratio of oil palm stem and mixed tropical hardwood sawmill. The fibre length values were 1.25 mm for oil palm stem and 1.18 mm for mixed tropical hardwood sawmill residues (Table 4). Both are within the range reported for short-fibre pulps (Akpabio 1989). The properties of products made from pulps from both sources can be enhanced by mixing with long-fibre pulps but the fibre lengths are definitely within the range that can provide fibreboard of good quality.

Table 5 presents the mechanical and physical properties of medium density dry-formed fibreboard and wet-formed hardboard with two smooth surfaces (S2S) and wet-formed hardboard with only one smooth surface (screen meshed surface on the reverse or S1S). These properties were found in all cases to be superior to the minimum property requirements recommended by American National Standard Institute ANSI A 2082 –1980 (ANSI 1980) for medium density fibreboard and PS 58–73 for hardboards (United States Department of Commerce 1973).

Table 4 Fibre length and width distribution and related fibre characteristics of *Elaeis guineensis* stem and those of tropical hardwood sawmill residue (all grown in Nigeria)

Fibre length distribution	Fibre length ranges as % of total fibre	Fibre width distribution (mm)	Fibre width ranges as % of total fibre	Length: width
Oil palm stem				
0.06 – 1.00	32.07	0.005 – 0.010	23.60	
1.01 – 1.50	51.80	0.011 – 0.015	55.10	
1.51 – 2.00	10.15	0.016 – 0.020	19.00	
2.01 – 2.50	5.08	0.021 – 0.025	1.70	
2.51 – 3.00	0.90	0.026 – 0.030	0.60	
Average 1.25	–	0.014	–	
Std deviation 0.206	–	0.0025	–	96.37
Mixed tropical hardwood sawmill residues				
0.06 – 1.00	39.19	0.005 – 0.010	8.96	
1.01 – 1.50	52.70	0.011 – 0.015	19.05	
1.51 – 2.00	5.65	0.016 – 0.020	34.66	
2.01 – 2.50	2.00	0.021 – 0.025	45.20	
2.51 – 3.00	0.46	0.026 – 0.030	2.13	
Average 1.18	–	0.021	–	
Std deviation 0.195	–	0.0039	–	60.40

Mean fiber lengths and widths are the weighted averages from 130 fibre measurements.
Length:width ratios were calculated using the mean fibre dimensions.

Table 5 Properties of fibreboards made from different furnishes *

Source of furnish	Type of board	Number of replicates	Board specific gravity	Mechanical property			Physical property	
				Modulus of rupture (MPa)	Modulus of elasticity (GPa)	Internal bond (MPa)	Water absorption(%)	Thickness swelling (%)
Oil palm stem								
	MDF **	10	0.7 (2.9)	43.02 (6.15)	4.864(7.11)	0.62 (5.84)	48(7.56)	16(6.37)
	Hardboard (S2S)	10	0.8 (3.62)	46.55 (5.76)	3.297(6.03)	0.48 (9.02)	54(10.20)	28(8.17)
	Hardboard (S1S)	10	0.8 (3.26)	34.22 (11.04)	2.868(10.61)	0.83 (7.10)	58(11.55)	32(8.00)
Tropical hardwood sawmill residues								
	MDF **	10	0.7(3.8)	50.54(7.13)	4.295(8.34)	0.54(7.00)	54(8.47)	18(11.20)
	Hardboard (S2S)	10	0.8(4.01)	52.54(8.85)	3.933(10.17)	0.50(11.06)	56(6.58)	30(10.08)
	Hardboard (S1S)	10	0.8(5.46)	28.68(13.10)	3.919(12.42)	0.76(5.22)	59(5.78)	29(9.41)
Randomly mixed furnish ***								
	MDF **	10	0.7(3.11)	46.00(6.45)	4.103(8.04)	0.41(6.51)	52(8.41)	16.5(9.15)
	Hardboard (S2S)	10	0.8(4.00)	49.11(7.92)	3.688(9.00)	0.55(11.41)	56(7.68)	28(8.60)
	Hardboard (S1S)	10	0.8(3.97)	38.05(11.50)	3.051(11.01)	0.78(6.42)	58(10.89)	30(11.81)

Values in parentheses are co-efficients of variation (%).

All materials used in these tests were conditioned at 65 ± 2% relative humidity and 20 ± 2 °C for two weeks before testing.

* = Pulp used for the manufacture of the various board types were generated from cold soda semi-chemical process.

** = Medium density fibreboard manufactured by dry process with 7.0% urea formaldehyde as binder.

*** = Randomly mixed furnished composed of pulp generated from random mixture of 30% tropical hardwood sawmill residues and 70% oil palm stem fibrous strands.

Medium density dry-formed fibreboard made from tropical hardwood sawmill residues exhibited superior MOR to MDF made from oil palm stem (Table 5). This difference was found significant at 0.05 level in a Tukey's Student test. This was not expected in view of the longer fibre length of oil palm stem furnish and known positive correlation between slenderness ratio and adhesive utilization efficiency in particleboards. One possible explanation is that the smaller diameter of the oil palm fibrous stem (fibre width = 0.014 mm as opposed to 0.021 mm for tropical hardwood sawmill residues) probably gave greater surface area for adhesive dosing. Thus, at the adhesive level used in this study, optimum quantity of adhesives required to achieve optimal bonding and consequently properties was not used for oil palm stem generated fibre. Another explanation is that fibres generated from the tropical hardwood sawmill residues probably have mean higher inherent strength (MOR). However, no significant difference (at 0.05 level) was observed in the MOE and internal bond strength (IB) of the boards from the three distinct furnish types.

The dimensional stability (linear and thickness swelling) and water absorption due to a 24-hour water soak were found not significantly different (at 0.05 level) irrespective of type of furnish used. Since the binder used was a UF adhesive (an interior glue) it could be explained that the prolonged soaking caused glue bond failures and consequently maximum water soak and dimensional movement.

In general, 0.8 specific gravity hardboard made of two smooth surface (S2S) exhibited superior MOR and MOE than 0.8 specific gravity hardboard of screen meshed back (S1S). These differences were significant (at 0.05 level) in Tukey's Student test. These differences could be attributed to the two smooth surfaces, which provided a more cohesive and integral face to resist stress as opposed to the screen-backed hardboard where the reverse face might incorporate micro cleavages. A close observation of the raw bending strength data indicates that with respect to the screen meshed back boards, the bending strength of half the total number of replicates tested was found to be lower when the screen meshed back were loaded in tension. Also, the smooth surface might have allowed for the flow of lignin during hot pressing and thus closed up interstices that might have otherwise been present on the surface of the reverse face had the board been screen meshed. The above, if it did occur, will enhance strength and possibly block unsaturated hydroxyl sites with consequent effects on water absorption and resultant dimensional movements.

However, the water absorption and consequent dimensional movement (linear and thickness swellings) were found not to be significantly different (at 0.05 level) between S2S boards. This could be attributed to the prolonged soaking in water which allowed for maximum absorption and consequent dimensional movement.

Conversely, screen meshed back hardboard (S1S) exhibited significantly superior (0.01 level) internal bond strength (IB) when compared with hardboard made of two smooth surface (S2S). This finding is in conformity with available records on hardboard properties (United States Department of Commerce 1973).

Conclusions

Cold soda pulps from either oil palm stem and / or mixed tropical hardwood sawmill residues used for the manufacture of dry-formed medium density fiberboard or wet-formed hardboard were suitable raw materials because of the acceptable properties of resultant boards.

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