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Investigation of properties of oil palm empty fruit bunch fiber in the strength and fracture performance of boards

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Abstract

The physico- chemical characteristics and economic relevance of Empty Fruit Bunch(EFB) of oil palm *(elaeis guineensis)* to the fiber board industry were investigated. Fiber dimension assessment was carried out to examine its lignin and cellulose content and estimate its suitability and potential as raw material for fibre and acoustic board production by comparing its examined properties with similar imported products. Sample preparation was conducted in accordance with TAPPI Standard T12 – OS – 75, which specifies that samples be ground to a fine particle size to permeate 0.4mm screen and retained on a 0.6mm screen. The moisture content, lignin, extractives, alpha cellulose, and ash content, fiber dimensions, and determination of cross and Bevan cellulose were investigated. Pulping operation was subsequently carried out. The results show that fiber yields were exceptionally high, with good strength properties. The maximum pulping temperature was 156^{o}C and the fiber yield obtained averaged 42.25%, calculated on oven dry (O.D) basis. Strength properties were determined after nine beating times and the results obtained were plotted against time. Fiber boards were produced with oil palm EFB and tests carried out at 20^{o}C and 65% relative humidity. The results indicate that the burst factor and tear index of oil palm EFB exhibited remarkable strength properties. Microscopic studies showed that EFB of oil palm contain 68 % medium fibre. The resultant pulp from the cooking operation had very good feel, and a fairly bright colour, thus asserting that oil palm wastes have a promising future as a substitute for wood in the fiber board industry.

Keywords: Alpha α- cellulose; lignin; TAPPI; white liquor; sulphidity; EFB; oil palm

1. Introduction

Oil palm trees are chiefly grown in the southern part of Nigeria, and other parts of West Africa .The palm oil and the palm kernel oil are the main products while the empty fruit bunches (EFB) constitute wastes. The discarded bunches of the oil palm are used as substitute for firewood while the sap of the tree serves as good source of palm wine. The residue from the oil - extraction process constitutes useful domestic needs and also provide valuable source of income for many small holders in a variety of ways. However, the percentage of these residue usefully utilized are quite low, the rest constitute waste and nuisance to the environment. The palm oil is extracted from the mesocarp (flesh), and the palm Kernel oil comes from the nut. The oils are used for cooking, manufacture of soap and margarine. Oil palms are an important crop. Oil palms produce edible oil (palm and kernel oil) in large quantities per unit of land than any plant. Despite its commercial importance, it is not a well- known plant in producing fiber for paper and board making (F.A.O.,2003).

In the building and construction industry, fiber board is a basic material. The development of well - developed machineries to produce it has been largely responsible for contributing to the provision of adequate shelter throughout the world. About 50% of the total cost of all constructions can be accounted for by building materials alone, and in low-income shelter, the value of building materials could be as high as 80% of total cost because of the relatively low requirements for other inputs, such as equipment, installations and specialized skills. This trend of rising costs and falling supplies of materials can be reversed, if the system of production is based on locally available resources (Elinwa and Buba, 2003). The responsibility for improving these situations rests, to large extent, on the ability of the construction industry to meet the demands for basic physical investment in the building environment. Given this pivotal role of construction in national development, the building materials constitutes the single largest input in construction.

Building materials have been a cause for inadequate construction output, high construction cost, abandonment of construction projects and sometimes inadequate building maintenance in developing countries (Elinwa and Uba, 2001). This situation has come about because majority of our basic building materials are imported at enormous cost to the economy.

Economic growth of a nation is directly related to the level and efficiency of capital formulation. Typical indicators of underdevelopment are inadequacies in physical infrastructure, shelter and related amenities. Nigeria is faced with many problems in which shelter provision is one of them, and so the next twenty to fifty years, the construction industry will still remain very viable and thus will need a lot of building materials as inputs (Elinwa and Mangvwat, 2004).

It is in recognition of these that alternative sources of suitable renewable materials becomes necessarily expedient for exploration. The oil palm (EFB) comes into useful need as an alternative to wood and other composite production materials for board production.

2. Materials and methods

2.1. Materials

The samples of oil palm trees felled within two weeks were obtained from Oke Ira in Ebute - Metta (West) Local Government Area of Lagos State and Gidan Kwano, Minna, Niger State, Nigeria.

2.2. Methods

Methods developed by Technical Association of the Australian and New Zealand Pulp and Paper Industry Inc.,(APPITA,2006) and the Technical Association of Pulp and Paper Industry (TAPPI,2004), were adopted.

2.2.1. Moisture content

The moisture content of sample was determined by measuring the weight loss after drying the sample at 105^{o}C, calculated on the basis of moisture –free wood (Newell, 2007).

2.2.2. Extractives

The solubility of wood in various solvent is a measure of the extraneous materials. The solubility of the sample in ethanol/toluene in a 1:2 volume ratio gave a measure of the extractives content. This procedure is TAPPI Standard (T204, 2004) and ASTM Standard (D-1107, 2006). The sample meal was refluxed for 8 hours in a soxhlet flask, and the weight loss of the extracted dried sample was measured (Casey, 2008).

2.2.3. Lignin

TAPPI Official Method was conducted for the Determination of Acid-insoluble Lignin in the samples (T222 om-88, 2004). The finely ground sample was treated with 72% H_2SO_4 for 2 hours at 20^{o}C. Followed by dilution to 3% H_2SO_4 and refluxing for 4 hours. To ascertain the validity of result obtained, an equivalent but shorter method was also employed. This was done by treating the sample with 72% H_2SO_4 at 30^{o}C for 1 hour, followed by 1 hour at 120^{o}C in 3% H_2SO_4. In both cases the determination was gravimetric (APPITA, 2006).

2.2.4. Ash analysis

Ash analysis was performed in accordance with TAPPI Standard T 15 and ASTM Standard D 1102. In these standards ash is defined as the residue remaining after dry ignition of the wood at 575^{o}C. Elemental composition of the ash is determined by dissolving the residue in concentrated HNO_3 and analyzing the solution by absorption or atomic emission. The inorganic elemental composition of the sample can be determined directly by neutron activation analysis (TAPPI-211-om-93, 2004)

2.2.5. Holocellulose

Holocelullose is the total polysaccharide (cellulose and hemicelluloses) content of the sample, and methods for its determination seek to remove all the lignin from the sample without disturbing the carbohydrates. The procedure adopted was TAPPI standard method (T-249, 2004) and ASTM Standard method (D-1104, 2006). Extracted sample meal was treated alternatively with chlorine gas and 2-amino ethanol until a white residue (holocellulose) remains. The acid chlorite method was also used (Saikia et al., 2006).

2.2.6. Alpha cellulose

Alpha cellulose was obtained after treatment of the holocellulose with 17.5% NaOH in accordance with ASTM Standard method (D-1103, 2006). This procedure removes mostof the hemicelluloses (Horn and Setterholm, 2003).

2.2.7. Fiber dimension

Fiber extraction analysis was carried out by macerating in the boiling mixture of Ethanol and Hydrogen peroxide in ratio 2 to 1. The fibers obtained were carefully mounted on a slide with aid of dissecting needle, and aligned for easier observation and measurement. About twenty fibres were measured per each sample at a magnification of X 101 on a Reichort Visopam projection microscope. All samples were measured in swollen condition.

2.2.8. Pulping

After a thorough cleaning process, 3kg of air-dry chips of the sample was loaded into the digester. The sample was covered with the cooking liquor of about 20% sulphidity, and the lid of the digester was firmly bolted to prevent leakage. The digester was switched-on and the time of rise and fall of temperature and pressure was noted at intervals of five minutes. The pulping temperature rose gradually up to 176^{o}C during a period of 45 minutes and remained steady. The pulping temperature, pressure and starting time were all noted, and the various changes in parameter were also recorded. Drop in the value of temperature of the operating digester indicated cessation of pulping operation. The digester was switched off, allowed to cool below 60^oC and the content blown down. Study of the graph derived from the values recorded during the pulping operation indicated that the overall cooking time was about 102 minutes to reach the maximum temperature of 176^oC.

2.2.9. Digestion of oil palm EFB residues

After a thorough cleaning process, 3kg of air-dry chips of the sample was loaded into the digester. The sample was covered with the cooking liquor of about 17% sulphidity, and the lid of the digester was firmly bolted to prevent leakage. The digester was switched on and the time of rise of temperature and pressure was noted at intervals of five minutes. The pulping temperatures rose gradually up to 138^oC during a period of 141 minutes and remain steady. The temperature however did not exceed 156^oC. the initial P^H of the pulping liquor was recorded at 6.0. The digester's initial temperature, pressure and starting time were all noted, and the various changes in parameters were also recorded. Drop in the value of temperature of the operating digester indicated cessation of pulping operation. The digester was switched off, allowed to cool below 60^oC and the content blown down.

The resultant pulp was subjected to thorough washing with enough water. When it was observed that subsequent washing resulted in no further change in colour. The pulp was subsequently transferred into the valley beater for processing into a more refined pulp for fiber extraction.

2.3. Production of oil palm EFB fiber board specimen

The oil palm EFB fibers were used in tangled mass and random orientation in the production of boards by hand lay-up technique. The 8% carboxyl methyl cellulose by weight of pulp slurry containing 12 kg/m^3 of mixture, and water-solid material ratio of 0.42 were mixed with the EFB fiber system, and conditioned for about 3 ½ hours before testing.

2.3. Testing

2.3.1. Determination of strength properties of oil palm EFB fiber

Strength properties were determined after nine beating times and the results obtained were plotted against time. Study of the graph derived from the values recorded during the pulping operation indicated that the cooking took about 105minutes to reach the maximum temperature of 156^oC.

2.3.2. Determination of mechanical strength properties of oil palm EFB boards

The mechanical strength properties of the oil palm EFB specimens were carried out using Instrom Testometer. A total of 16 boards were formed and cured for 5 and 12 days for each mixture, the flexural strength of two boards were loaded investigated, and the average strength was recorded in each case. The results are shown in Table 3. Three – Point Test Method was adopted during the Flexural strength property test with 40.00 mm/min speed on 150mm span of rectangular sample. The tensile strength test was ran on 50.00mm/min speed on 100mm span irregular test sample.

3. Results

Tables 1 – 3 show the results of mechanical strength properties of oil palm EFB fiber systems, while the results of mechanical property tests conducted on the oil palm EFB fiber board samples are presented in tables 4 and 5.

Table 1
Result of processing parameters of oil palm EFB fibers

Parameter	Oil palm (EFB)
Source of Sample (Geographical Location)	Nigeria (Coast of West Africa)
Age of maturity (years)	6-8
Moisture content of wood sample (wt %)	23.63
Ash content (wt %)	4.6
Acid insoluble lignin (wt%)	18.09
Extractives (wt%)	13.65
Fiber length (mm)	1.75
Alpha (α) – cellulose (wt%)	45.57
$NaOH – Na_2S$ ratio	4:1
Air-dry weight of chips (kg)	3.0
pH of cooking liquor (white liquor)	6.0
Percentage sulphidity (%)	15
Wood-liquor ratio	1:5
P^H of spent liquor (Black liquor)	3.0

Time to reach max. Temp. of digester (minute)	85
Max. Temp. of digester (^{O}C)	156
Time at max. Tempt. of digestion (minutes)	40
Overall cooking time (minutes)	108

Table 2
Result of bulk density test of oil palm EFB fibers

Sample	Density (g/cm^3)
1	1.2069
2	1.2677
3	1.0919
4	1.0890
5	1.1216
Average value =1.1554 (g/cm^3)	

Table 3
Result of average value of oil palm EFB fibers characteristics

Sample	L(mm) Fiber Length	D (µ) Fiber diameter	L (µ) Lumen diameter	W (µ) Cell wall thickness	2w/l Runkel Ratio	L/D Slenderness Ratio	W/D Flexibility coefficient
1	1.373	62.250	28.826	20.030	1.390	20.388	0.2776
2	1.457	68.560	27.365	22.250	1.626	65.573	0.3231
3	1.286	72.400	29.753	23.500	1.580	20.385	0.3237
Average value	1.372	67.736	28.648	21.927	1.410	35.449	0.3081

Table 4
Result of flexural strength properties of oil palm EFB fiberboards

Parameter	Board sample
Width (mm)	50.000
Thickness (mm)	8.000
Force at peak (N)	210.20
Deflection at peak (mm)	6.4080
Bending Strength at peak (N/ mm^2)	14.780
Energy at peak (N.m)	0.7931
Force at break (N)	126.10
Deflection at Break (mm)	15.648
Bending Strength at Break (N/mm^2)	8.8664
Energy at Break (N.m)	2.4552
Bending Modulus (N/mm^2)	1274.9
Force at Yield (N)	210.20
Bending Strength at Yield (N/mm^2)	14.780
Deflection at Yield (mm)	6.4080

Table 5
Result of tensile strength properties of oil palm EFB fiber boards

Parameter	Board sample
Area (mm)	550.000
Force at peak N	51.300
Elongation at peak (mm)	0.4220
Stress at peak (N/mm^2)	0.0933

Energy at peak N.m	0.0068
Force at break (N)	3.6000
Elongation at break (mm)	2.0670
Stress at break (N/mm^2)	0.0065
Energy to Break (N.m)	0.0292
Force at Yield (N)	51.300
Elongation at Yield (mm)	0.4220
Stress at Yield (N/mm^2)	0.0933
Young's Modulus (N/mm^2)	37.602

4. Discussion of results

It is observed that during the pulping operation, the pH of the cooking liquor dropped from 6.0 to 3.0 indicating that the sodium sulphide (Na_2S) performs certain functions besides that of increasing the hydroxide content of the liquor. This generally responsible for the increase in rate of lignin removal. There is also the suspicion that the presence of NaSH resulting in NaS, made the lignin to be more soluble.

From Table 1, it is shown that the acid-insoluble lignin in the oil palm EFB fiber was determined to be 18.09%. This necessitated the use of a mild liquor of 15% sulphidity for the cooking operation. It is noted of interest that a sulphidity of 5% in alkaline liquor caused an appreciable increase in the rate of removal of lignin as compared with no sulphidity in the liquor.

Similarly, Table 1 showed that the ash content of the oil palm EFB fiber gave 4.6 which is a measure of inorganic mineral present in the sample, which afforded more effective reuse of spent chemical after the pulping operation.

The average fiber length of 1.75mm is similar to those of other researchers. The alpha cellulose content recorded value of 45.57% is indicative of the amount of un-degraded higher molecular weight cellulose present. Beta-cellulose recorded 10.08% indicating the measure of the amount of degraded cellulose in the specimen while Gamma-cellulose recorded 1.76% indicating the amount of hemicellulose present.

The approximate pulp yield of 65% was outstanding. Temperature coefficient of delignification was determined to be approximately 2.0, indicating that an increase in cooking temperature by10% could results in a doubling of the rate of lignin removal. However, a negative correlation between the strength properties of pulp and the yield suggests that the strength of the pulp depends on the quantity of reaction sample fiber.

The average density value of 1.1554 g/cm^3 in table 2 is consistent with other researcher's findings. Table 3 showed slenderness ratio and flexibility coefficient are generally dependent on fiber dimensions, which have effect on the strength properties of the fiber board.

From Tables 4 and 5, it is evident that the oil palm EFB fiber boards exhibited outstanding mechanical property values of 14.78 N/mm^2 and 0.0933 N/mm^2 for the flexural and tensile strengths respectively.

5. Conclusion

From the processing and test results carried-out on both the oil palm EFB fiber and oil palm EFB fiber boards, it can be inferred that:

- Tensile strength increased with degree of fibre fibrillation and time of pulp beating up to a certain point, and then decreased sharply at first and then very gradually until it became constant. This gradual failure pattern is important in predicting the behaviour of oil palm EFB fiber in board application.
- The outstanding mechanical properties of oil palm EFB fiber boards makes these natural materials suitable for application in the production of boards for use in ceilings and other less structural building applications.
- Oil palm EFB fiber, presently regarded as wastes, could be converted into useful economy while solving the environmental problems often cause by their improper disposal, and most importantly, achieve the 'waste – to – wealth" quest.

Recommendation

It is recommended that emphasis be placed on the use of oil palm EFB fiber production for the production of fiber boards at the conditions under which this work was performed.

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