The Influence of Fiber Density and Cellulose Content of Banana and Rice Straw Fibers on Fiber Processing and Flexural Strength

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ABSTRACT

Excessive use of wood based fibers and inefficient management of forest reserves contribute critically to shortage of trees. Abandoned biomass, banana and rice straw, are considered as alternatives for wood in lamina or ply composite industry. Key objective of the study is to reduce the fiber strands into particulate mechanically. It also delved on investigating the influence of fiber density and cellulose content on fiber particulate recovery and flexural strength. In line with this, the study also investigated whether natural fibers in particulate form can be consolidated in sand cement mortar. Toward this end, fibers were extracted and processed mechanically through hammer and milling actions. Buoyancy principle is utilized to find the specific gravity of the fibers then converted into fiber density. Fiber cellulose content is resourced. Sample deflection is obtained from three point bending test. Flexural strength is calculated utilizing the theoretical deflection equation. An attempt is made to integrate the fibers in sand cement composite lamina. Samples are prepared and conditioned as air dried.

Results indicated banana fiber exhibited higher density than rice straw fiber. Fiber particulate as produced mechanically showed that banana fibers are coarser than rice straw fibers. When milled and screened, banana fibers exhibited higher recovery rate of 89.4 percent, compared to rice-straw with 63.1 percent. Findings also revealed that flexural strength increased with increasing specific cellulose, ratio of cellulose content and fiber density. Particulate banana and rice straw fibers at 30 percent by weight are better consolidated in 1:3 cement sand mixture. Thus, cellulose content and density of the fibers are important parameters in mechanical extraction. The degree of difficulty and rate of recovery are relatively proportional to these parameters. Consolidating 30 percent of fiber particulate with sand and water-cement ratio was successfully attempted. The fibers in particulate form exhibited characteristics conducive for ply board production.

KEYWORDS: biomass density particulate composite lamina flexural strength.

1. INTRODUCTION

The global occurrence of wood-based ligno-cellulosic fiber is still adequate and there is today no general fibre shortage or crises. Yet at the same time, we have some regional deficiency of wood-based fibers. Industrial demand of proper wood based raw materials is critical in several Asian countries. The strong economic growth in Asia has contributed to increased demand of wood-based raw materials. Wood-based biomass is becoming more restricted and expensive for producers of pulp and paper, bio-energy, lumber, and wood-based composite fiber boards. Moreover, the increasing environmental awareness and concerns of the health of forests, wildlife diversity, biomass productivity, climate, and the biological sink directs research to alternative fiber recourses. Considerable research effort had been done to find some alternate fibers, such as natural fibers. Natural fibers, however, have a classic problem of variability in fiber properties. Banana and rice straw are naturally occurring composite material. They grow abundantly in most of the tropical countries. It is considered a composite material because the fiber consists of cellulose fiber imbedded in a lignin matrix. The major elements in its chemical composition are cellulose 63 to 64 percent and lignin, 5 percent. Banana fiber is a natural leaf fiber with an average fiber length of about 2mm, a diameter of 12 to 30µm, and a tensile strength ranging from 520 MPa to 750 MPa and a density of about 1.35 g/cm^3. Banana is the common name for herbaceous plants of the genus musa family musaceae and is also the name given to the fruit of this plant[1]. Banana fiber is a natural bast fiber. Compiled from Philippines Textile Research Institute[2], and from Thailand Textile Institute[3] banana fiber has 61.5% alpha cellulose, and 15% lignin. In his study, Banana fiber strands was successfully consolidated into composite lamina[4].

The purpose of the study, was to consider natural fibers in its technical form, reduced to particulate to be used as major constituent in lamina composites. This was done by reducing mechanically the fiber strands into fiber particulate and simultaneously investigate their particulate recovery and flexural modulus characteristics as a function of fiber density and cellulose content. Fiber strand extraction was facilitated manually for sampling purposes, primarily by hammering and milling. Consequently, a composite lamina was developed to demonstrate the possibility of consolidating the fiber particulate with sand cement paste as the matrix or adhesive. In line with this a critical volume fraction has to be considered to ascertain a homogeneous panel board.

2. MATERIALS & METHODS

The natural fibers investigated in this study were taken from banana and rice straw, considered to have a cellulose structure as mentioned by Eichhorn S J, et al.[5], Shiraishi N.[6], and Olesen [7]. Cellulose, a primary component of the fibre, is a linear condensation polymer consisting of Danhydro-glucopyranose units joined together by ß-1, 4-glucosidic bonds. The long chains of cellulose are linked together in bundles called micro-fibrils. Hemicelluloses are also found in all plant fibres shown in Figure 1.

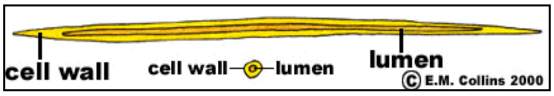

Figure 1. Longitudinal and Cross-section of a Fibre Cell *[Afa Austin Waifielate Bolarinma Oluseun Abiola (2008)*

In many countries, straw is an abundant cellulosic by-product from the production of crops such as wheat, corn, soybean and rice. The natural fiber comes from stalks, leaves, and seeds, such as kenaf, sisal, flax, wheat straw and rice straw[8]. It represents around 45% of the volume in rice production, producing the largest quantity of crop residue. Rice straw has the most amount of cellulose from agricultural crop residues because its composition is cellulose (38.3%), hemicelluloses (31.6%) and lignin (11.8%)[9]. Furthermore, Sridach[10] mentioned rice straw has alpha cellulose 28-36%, and lignin 12-16%, and banana alpha cellulose 55-65%, and lignin 2-4%.

2.1 Fiber density

Studies showed inconsistent results of fiber density in natural fiber. Manohar[11] investigated specific gravity measurements in accordance with ASTM D-792, through buoyancy tests with water as the medium for immersion. The same concept was used to set up the apparatus in this study. It consisted of an electronic balance with a sample holder attached to a metal frame acting as a inker. The sinker, while resting on the balance, was used to immerse the specimen completely into the water bath. With no specimen in the sample holder, the sinker and sample holder were immersed in the water bath and the balance set to zero. The sinker with the sample holder was then withdrawn from the water bath and a randomly the selected weighed fiber specimen placed in mesh holder. Together, it was then immersed into the water within 10 seconds and the apparent mass recorded. The time of immersion minimized soaking of fibers with water. The specific gravity was determined and the fiber density was calculated using the appropriate equation with density of water taken at 24^{O}C.

2.2 Weighted Proportions

In order to design a composite lamina with specific ratios of natural fiber strand, proportions of fiber and matrix has to be properly evaluated base on the properties of each constituent. Prior knowledge about the properties of the constituents is required before the lamina is fabricated. Unfortunately, neither the banana fiber nor the rice straw has uniform cross section which makes the determination of fiber volume fraction difficult. The weight of these materials however, can be conveniently found by standard weighing procedure. This weight can be converted into volume fraction using Equation 1, when desired. Tobias (2001) relates the significant relationship between the fiber weight (w_f), fiber volume fraction (v_f), filler volume fraction (v_r), matrix volume fraction (v_m), fiber density (r_f), and matrix density (r_m), given in Equation 1.

$$v_f=(w_f/\rho_f)/(w_f/\rho_m+(1-w_f)/\rho_m) \qquad (1)$$

2.3 Medium density panel board

Figure 2 delineates orthogonal properties when the panel board is designed and developed. The mechanical properties have to be uniformed in all directions. Homogeneity, even dispersion of fiber particulate, is an important parameter. This is conceptualized that the flexural strength, E, of the panel board is the same in x, y, and z direction. By the rule of mixture, Equation 2, it implies that:

$$E_{panel\ board} = E_x = E_y = E_z = E_f\, v_f + E_m\, v_m, \qquad (2)$$

where subscript f and m stands for fiber and matrix, respectively

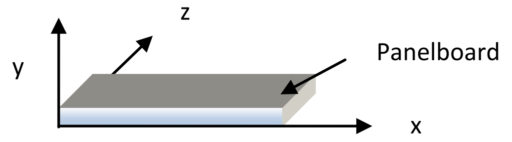

Figure 2. Orthogonal manifestation of composite lamina

Equation 2 implies that for the lamina to be homogeneous, its properties should be similar in orthogonal components. The property measured in this study is modulus of elasticity.

2.4 Experimentation

An experimental method was carried out to generate data that could support the output of the study. Included was an experimental observation required to qualitatively assess the mechanical extraction of the fibers. Scientific observation is predominant in some steps of the research process. It serves as the foundation of correct and accurate information. Description clarifies or pictures the information accumulated through observation.

2.5 Microfiber extraction

Growing worldwide importance of the utilization of various non-wood plant fibers, as an alternative to wood pulp, in the manufacture of pulp, paper and paper board is now well established. Many non-wood fibers such as bamboo, jute, straw, rice, and abaca are currently used in small commercial pulping operation.

Pulping is done to liberate the fibers from lignin and hemicelluloses, which can be accomplished chemically or mechanically or by combining these two type of treatment. Mechanical pulping is characterized by the use of kinematics & dynamics mechanism, to separate the lignin fraction of lignocelluloses materials from the cellulose.

Mechanical pulping has been considered a sound solution for micro-fiber extraction. Pulping is a process to liberate the fibers from lignin and hemicelluloses, which can be accomplished chemically or thermally or by combining these two types of treatment. Mechanical pulping, however, was facilitated by the use of kinematics and dynamics mechanism, to separate the lignin fraction of lignocelluloses materials from the cellulose. The separation of lignin from lignocelluloses biomass has been well documented using the chemical process and by organic solvent. Numerous attempts were made in pulping process using different solvent system to selectively separate cellulose, hemicelluloses and lignin even using the stem of fiber crop. This study used six step process or pulping techniques. In essence, micro-fiber as defined in this study has been considered as particulate with 425µm size. The sequence of events started with extraction of fiber strands from raw materials, followed by cutting of strands into short fibers, de-lignition or size reduction through hammering and milling, screening with 40 mesh sieve, and finally storing of particulate. This supply complimented the size of fine sand, as the other constituent for composite lamina. Foremost, the study eliminated the use of chemical application during the de-lignition process.

2.6 Flexural Test

The flexural properties of the composite lamina were obtained by three-point bending configuration in accordance with ASTM-D70-81. The flexural strength was calculated as the modulus of rupture (MOR) in three-point bending using Equation 3, where *P* is the maximum load recorded during the test, *l* is the specimen span, *b* is the specimen width and *d* is the specimen depth. In this study a span of 70 mm was considered.

$$MOR = \frac{3Pl}{2bd^2} \qquad (3)$$

3. RESULTS AND DISCUSSION

As shown in Table 1, which was graphically translated into Figure 4, banana fiber has higher density of 425.9kg/m^3, as compared with rice straw with 398.29kg/m^3. The natural fibers showed slight significant difference in the fiber densities. The relative accuracy of test results in fiber density measurements, based on buoyancy procedure was statistically inferred in Table 1. This showed that natural fibers have varying degree of uncertainties in relation to fiber source and type. The results also inferred the influence of cellulose content. The higher percentage of cellulose content the denser was the fiber.

Take the case of banana fiber against rice-straw fiber. Shidach[10] found in his study the alpha cellulose content of banana fiber or hemp bast type, 65% whereas, rice-straw, 36%, in the upper range. In this study, banana fiber density 425.9kg/m^3, and rice-straw 398.2 kg/m^3, a difference of 6.5%. On these bases it was found that banana fiber has higher cellulose content to weight ratio of 15.3% as compared to rice-straw of 9.0%, a difference of 41.2%. This showed that when cellulose content to density ratio was taken into account, the difference became significant.

Table 1. Solid fiber strand specific gravity test

Test number	Banana	Rice straw
1	0.1607	0.2128
2	0.2000	0.3636
3	0.3636	0.4194
4	0.1089	0.3529
5	1.4286	0.3704
6	0.4651	0.4500
7	0.3636	0.6250
8	0.2500	0.4400
9	0.2143	0.3571
10	0.7143	0.4000
ave.spgr	0.4269	0.3991
ave.density (kg/m^3)	425.9	398.2

It has been observed that the strand contains micro-cells, which can also be manually extracted. It was through this observation that the micro-fiber mechanical separation was conceptualized. The results of the initial step in fiber size reduction are shown in Figures 5, 6, and 7. They were achieved by cutting the strands into short fibers, followed by hammering or pounding for 1 minute with controlled intensity. The fibers were then milled in two passes.

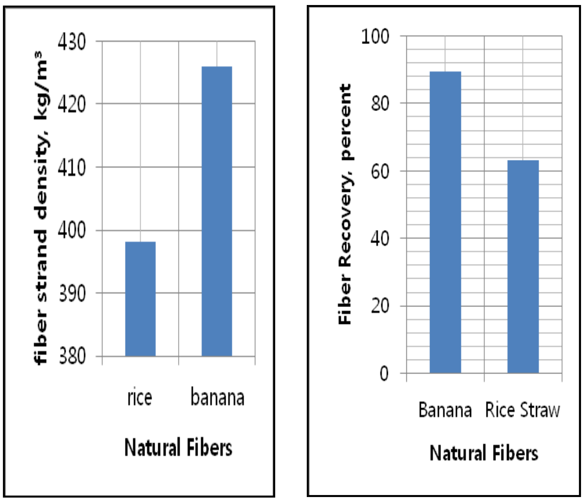

Figure 3. Banana fiber higher recovery rate and higher density

The results showed different levels of size reduction, as shown, with banana fiber, Figure 5, and rice -straw fiber, Figure 7, giving the distinctive appearance and reduction in size.

Figure 3 delineates that banana fiber has the most recovered, 89.4%, while rice-straw is having the least recovered, 63.1%. When measured against the cellulose content, the results showed that high cellulose content gives high recovery rate. Also as delineated in Figure 3, the fiber particulate recovery from fiber strands, the fibers exhibited significant difference, when all screened in No.40 mesh sieve. The results inferred that fibers of these types have significant difference in their densities and recovery factor but to a lesser extent. Indeed the fibers were successfully extracted and turned into fine particles by mechanical means.

Figure 4. Banana fiber strands 1minute and double pass milled hammered

Figure 5. Banana micro -fibers through No. 40 sieve screened hammered

The degree of difficulty in hammering and milling of natural fibers was again influenced by the cellulose content and density of the fibers. High cellulose content exhibited more difficulty in reducing the size. As a result, size reduction with uniform distinction was done through the process of screening.

Figures 5 and 7 showed the results after the screening process. As observed, and shown in Figure 4 and Figure 6, banana fiber is coarser than rice straw fiber. As figured out, the natural fiber has relative amount of particulate. Noticeably, in terms of their recovery, the fibers were all reduced to particulate size but with different amount. Quantifying such parameter was done through the recovery factor. In this case a measure of particulate weight against the original weight of the short fibers.

Figure 6. Rice straw hammered 1minute and double pass milled

Figure 7. Rice straw micro-fibers screened through No. 40 sieve

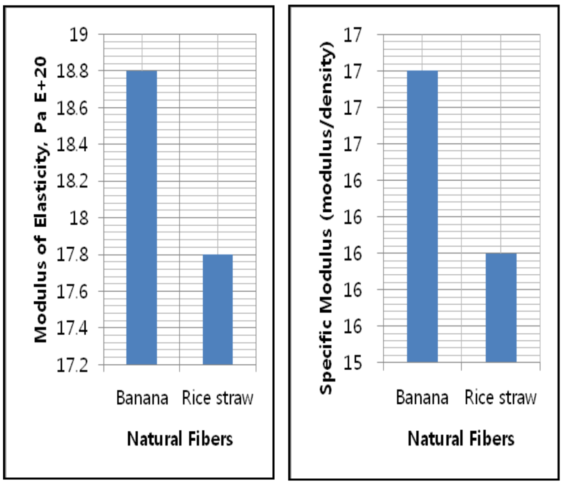

Figure 8. Banana fiber higher modulus than rice straw fiber

The flexural modulus of banana and rice straw fibers were also influenced by specific cellulose content, which is a measure of modulus over density. As delineated in Figure 8, the higher density is proportional to fiber cellulose content. This relationship was found to be in direct correlation with flexural properties of the fibers. The effect of fiber density was significant in bending test results, in particular the modulus of elasticity.

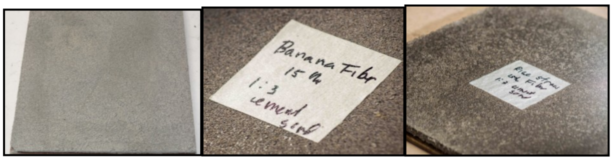

Figure 9. Consolidated natural fiber particulate in cement-sand matrix

Figure 9 showed the technical transformation of panel board from mortar Investigated in prior study, a 1:3 cement sand mortal (left) was considered appropriate. In this matrix, 30% by weight (15percent by volume) of banana (middle) and rice straw (right) fiber particulate have been successfully added as a constitute in the composite. As expressed in Equation 1, the volume fraction of fiber is a function of both fiber density and weight fraction. Thus fiber density could dictate the fiber critical volume fraction that can be consolidated soundly. with homogeneous property.

4. CONCLUSION

Cellulose content and density of the fibers are important parameters in mechanical extraction. Fiber cellulose content and fiber density influenced the fiber strand and processed particulate. Accordingly, the higher the ratio, cellulose content to density, the more difficult to extract the fibers. On the other hand, higher recovery rate of fiber particulate exhibited at higher ratio. When measured against the specific cellulose content in terms of flexural property, the banana fibers performed better than rice straw fibers. Consolidating 30 percent of fiber particulate with 1:3 cement sand ratio was successfully attempted. The fibers in particulate form exhibited characteristics conducive for ply board production.

REFERENCES

[1] Huther, AM. 1998. *Utilization of annual plants agricultural residues for the production of pulp and paper.* TAPPI pulping conference. P.39.

[2] Philippine Textile Research Institute, 2005, *Fiber properties*

[3] Thailand Textile Institute, 2008

[4] TOBIAS, BC. 2001. *Banana fiber consolidated composite lamina, 8th annual international conference on composite engineering,* Tenerife Island, Spain.

[5] EICHHORN S J, et al, 2001, *Review current international research into cellulosic fibres and composites*.Journal of Material Science and technology,36, 2107-213

[6] SHIRAISHI, N., 2001 Wood and cellulosic chemistry, 2 ed.. Marcel Dekker: New York

[7] OLESEN, P.O. 1999. *Perspectives on the performance of natural plant fibres*. The Royal Veterinary and Agricultural University, Taastrup, Denmark. Conference 27 – 28 May, Copenhagen, Denmark

[8] GARSIA, M. et al. 2008, *Influence of natural fiber type in eco-composites.* J. Appl. Polym. Sci. 107, 2994–3004.

[9] HESSIEN, M.M. et al. 2009, *Controlling the synthesis conditions for silica nanosphere from semi-burned rice straw.* J. Mater. Sci. Eng.162, 14–21

[10] SHIDACH, W, 2010, *The environmentally benign pulping process of non-wood fibers,* Suranaree J. Sci. Tech. 17(2):105-123.

[11] MANOHAR, K., 2012, *Experimental investigation of building thermal insulation from agricultural by-products,* British Journal of Applied Science & Technology, 2(3): 227-238.