Technical Paper

Special articles: JCREN Ⅲ
特集：JCREN Ⅲ

Influence of Pressing Pressure on the Mechanical Properties of *Durio zibethinus* (Durian) Fiberboard

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(Received January 5, 2022)

Medium-density fiberboard (MDF) was developed from *Durio zibethinus* (durian) husk using urea formaldehyde (UF) as binder. The output will be applied as an automotive panel, realigning the conventional application of MDFs. Fibers were recovered from the husk, the undersize of 10 mesh screen was used for board production. The optimal conditions were determined by different mixing ratios of UF with water and varying the pressing pressure. The undersized fibers and optimized board were characterized in terms of surface morphology. Moreover, the mechanical properties of fiberboards were also studied. Results showed that fiberboard was optimal at a press pressure of 640 kPa. It yielded an internal bond (IB) of 2.85±0.43 MPa, modulus of elasticity (MOE) of 3008±228.69 MPa, and modulus of rupture (MOR) of 22.25±2.61 MPa. These were compared against properties of commercial MDF based on American National Standards Institute (ANSI) specifications (IB≥0.6 MPa, MOE≥2500 MPa, and MOR≥22 MPa). Hence, these results proved that the optimized fiberboard has high potential for commercial application in the automotive industry.

Key Words

Automotive industry, Durian, Fiberboard, Husk, Urea formaldehyde

1. Introduction

Durian (*Durio zibethinus*) is one of Southeast Asia's most highly valued and desired fruits. It is called the 'King of Fruits' 1) 2) and is also tagged as 'civet cat fruit' due to its excellent, unique flavor with offensive odor 2). Out of all the Durio genus, 27 species are found at the center of Asia; and of the 27 species, *Durio zibethinus* is widely grown and cultivated in the Philippines. Durian is considered the flagship of Mindanao 1). As of 2016, the area where durian was planted in the Philippines was estimated to be 16,618.86 ha with a total of 1,265,890 bearing trees. Davao Region has the largest site where durian (*Durio zibethinus Murr.*) was planted, with 8,344.00 ha or 50.21 % of the national total, with 818,270 bearing trees 3). Most of the production is concentrated around Davao City 4). 2,800 ha of land where durian was planted remained in the city of ~16,600 ha nationwide 5). 23 cultivars of fruit-bearing durian exist at the University of Southern Mindanao (USM) clonal garden 1).

The durian fruit comprises 40% of flesh and 60% of the husk 6). The durian husk consists of 60.45% of cellulose, 15.45% lignin, and 13.09% hemicellulose, and the contents are similar to wood fiber 6) 7). The top 4 durian producers in the world (Thailand, Indonesia, Malaysia, and the Philippines) are all located in Southeast Asia, and they have a combined durian production of more than 1,600,000 t annually 8). Countries in southeast Asia can produce durian up to 900,000 t/year in the next 20 years 9). In the Philippine setting, the total durian wastes generated is approximately 39,874 t, where 39,700 t are generated from Mindanao, and from that figure, 31,100 t are generated from Region XI alone 10). Usually, the durian husks are discarded and end up in landfills or are burnt, posing environmental issues 6). According to Article 3, Section 20 of RA 8749, also known as the Philippine Clean Air Act of 1999, mass incineration of these municipal wastes, which may include agricultural wastes, is banned, as it emits combustion

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products detrimental to the environment [11]. Instead of ending in landfills, these indigenous wastes can be upcycled to replace wood in several applications.

The use of wood in various industries has long been established [12]. However, there is more interest in the global warming effect and campaigns for green areas and anti-deforestation in every country. There is a tendency to use raw materials from the leftovers of agricultural operation or consumption to replace natural wood. These alternatives for wood include chaff, straw, corn stalk, pineapple rind, and durian rind [6]. Durian is a suitable raw material because of its low thermal conductivity [13], good fiber strength, and being highly lignocellulosic which can be cross-linked during hot pressing to yield good mechanical properties of board [14]. The use of natural fibers in composites have substituted synthetic fibers in order to achieve renewable and biodegradable products with fewer costs and weights desired for many applications such as in the automotive industry.

The main area of increasing usage of biocomposites predominantly lies with the automotive industry as they result in significant weight savings of automotives corresponding cost savings on fuel consumption. The end-of-life vehicle (ELV) directive by European Union stated that by 2015, vehicles must be constructed of 95% recyclable materials, with 85% recoverable through reuse or mechanical recycling and 10% through energy recovery or thermal recycling, and led to a tremendous usage of biocomposites in automotives. According to a report on Global Natural Fiber Composites Market 2014-2019: Trends, Forecast and Opportunity Analysis, the market for biocomposites was forecasted to be worth 531.2 million USD by 2016 with an expected annual growth rate of 11% during 2014-2019 [15].

The main objective of this study was to produce a urea formaldehyde (UF)-binded medium-density fiberboard (MDF), a composite panel with density between 500-1000 kg/m [3] [16] from lignocellulosic durian fiber. The produced fiberboard will then be used as an automotive skin material. Specifically, this study aims to characterize the fiber and optimized fiberboard in terms of surface morphology; and determine the fiberboard's mechanical properties in terms of internal bond (IB), modulus of elasticity (MOE), and modulus of rupture (MOR). The obtained mechanical properties were compared against American National Standards Institute (ANSI) 208.2-2016 specifications. ANSI is a private, non-profit organization that provides a framework for fair standards development and quality conformity assessment systems.

2. Experimental

2.1 Materials

Durian husks were collected from Magsaysay Fruit Vendors Association in Davao City, Philippines. A 10-mesh sieve was also used for screening. A hygrometer (FY-12, China) was used to check the temperature and relative humidity (RH) of air. Blender (Electrolux EBR2001, China) was used to reduce the particle size of fibers. UF (<0.1 % formaldehyde, UNICOL Adhesive Technologies, Italy) was used as binder. The hydraulic press used for pressing was a product from Shimadzu (Shimadzu UMH-100) [17]. A moisture meter (MD-4G, China) was used to check the moisture of fibers and boards. A digital microscope (Carl Zeiss Axio Scope A1, Germany) was used to study the surface morphology of the fibers and boards. A Universal Testing Machine (UTM) (Jinan Liangong Testing Technology Co., Ltd, WEW-1000B, China) was used to determine the mechanical properties of the fiberboard. Vernier caliper was used for the measurement of specimen dimensions for better precision.

2.2 Methods and procedures

2.2.1 Fiber extraction

About 6 kg of collected durian husks were washed with running water for 30 min and brushed for another 30 min to remove dirt. The cleaned husks were boiled (100 °C for 30 min), manually pressed to remove gums, and washed with running water (moderate flow rate, 1 h) to recover the lignocellulosic fiber. Washing was continued until the slimy texture was no longer observed. The wet fibers were trimmed to smaller sizes, and sun-dried for about 3 d or until essentially dry. The fibers were stored at room temperature and ≥65 % RH. Then, the fibers were blended for 5 min to deagglomerate and reduce their particle size and screened (10-mesh screen). The undersized fibers were then used for fiberboard production. Samples of sieved fibers were saved for characterization.

2.2.2 Fiberboard Production

Ratio of fiber to resin by mass was fixed to 1:4. Adhesive was prepared by mixing 1.6 kg UF (<0.1% formaldehyde) with 2.4 kg water. The paste was homogenously mixed with 400 g fibers and was formed into a mat with dimensions 50 cm × 50 cm × 1 cm. The formed mat was subjected to varying cold press pressure (**Table 1**) for 2 min at room temperature [18]. These pressures were selected considering the capacity of the UTM. The pressing pressures selected were relatively higher than those in literature [7] [19]. The pressed mat was then conditioned at 20 °C and 65% RH overnight, and hot pressed (150 °) until all parts of the mat were heated. The hot-pressed panel was then stored in a room at 20 °C and 65%

Table 1 Experimental points of board production

Expt Pt	Fiber:Resin Ratio	Cold Press T (°C)	Hot Press T (°C)	Pressure (kPa)
1	1:4	20	150	520
2	1:4	20	150	640
3	1:4	20	150	760

RH for two weeks [18] [19] until the board was essentially dry and hard. After conditioning, the panel was then cut to specimen size based on ASTM requirements, characterized, and compared to MDF specifications set by ANSI 208.2-2016 [19].

2.2.3 Testing procedures for mechanical properties

Three mechanical properties were tested, namely: IB, MOE, and MOR. The mechanical properties were tested using the UTM. All test procedures were in reference to ASTM D 1037-12.

For the IB and MOE test, the specimen (Fig. 1) was 50 mm × 50 mm in size, with all four edges smoothly and squarely trimmed, and the thickness was that of the finished board. Cross-sectional dimensions of the specimen were measured to an accuracy of not more than ±3 %. Tension load was applied vertically to the board face, the maximum load (F) at the time of failing force (breading load of perpendicular tensile strength to the board) was measured, and the IB using equation (1) was calculated. In this test, the tension loading speed was approximately 2 mm/min [20] [21]:

$$IB = \frac{F}{b \times d} \tag{1}$$

where F [N] is the maximum load, b [mm] is the width of the test piece, and d [mm] is the depth of the test piece. IB of board at different experimental points were tested in at least triplicates.

The MOE for each specimen was calculated by using the equation:

$$MOE = \frac{FL_1}{A\delta} \tag{2}$$

where F [N] is the load at the proportional limit, L_1 [mm] is the length of the test piece, A [mm^2] is the cross-sectional area perpendicular to the applied load, and δ [mm] is the deformation at the proportional limit. MOE of board at different experimental points were tested in at least triplicates.

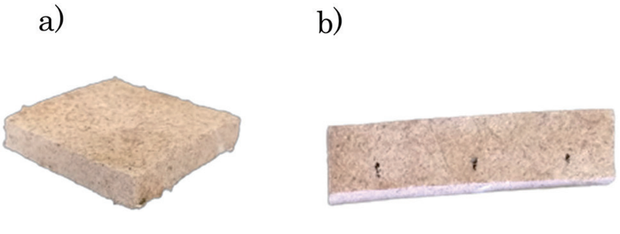

Fig. 1 Board specimen for (a) IB, MOE and (b) MOR tests

For MOR by static bend test, each specimen (Fig. 1) was 12 cm in length and 3 cm in width. The depth (thickness) was the thickness of the material. Each specimen's length, width, and thickness were measured to an accuracy of not more than ±3 %. The load was applied at approximately 2 mm/min at a mean deformation speed from the surface of the test piece and to measure the maximum load (F) [19].

MOR was calculated by using the formula:

$$MOR = \frac{3FL_2}{2bd^2} \tag{3}$$

where F [N] is the maximum load, L_2 [mm] is the span, b [mm] is the width of the test piece, and d [mm] is the thickness of the test piece [20]. MOR of board at different experimental points were tested in at least triplicates.

2.3 Statistical analysis

Mean was used to calculate the average of specimens per parameter. Standard deviation was used to determine the level of variation of data per parameter. The obtained data were statistically analyzed by using the one-way analysis of variance (ANOVA).

3. Results and Discussions

3.1 Characterization

3.1.1 Surface morphology

To explain these mechanical properties of the fiberboards, it is necessary to understand better the surface morphology and bonding mechanism between fibers during pressing. The surface morphology of fibers at different magnifications (1x-4.5x) were observed using a digital microscope (Fig. 2). The micrograph of durian rinds fiber showed an elongated fiber line, with a mean length of 8.71±2.37 mm (Fig. 3). Moreover, the fibers were found to have a mean diameter of 0.23±0.07 mm (Fig. 4). The microstructure of optimized fiberboard at 640 kPa was also observed at different magnifications (Fig. 5). These show the distribution of fibers in the board and how these fibers were agglomerated together using UF as resin.

It is well known that the values of mechanical properties depend on: (1) the bonding strength among fibers and (2) individual fiber strength [18]. Better inter-fiber bonds were the main factor responsible for improving bending strength, as the fibers used were of the same quality. These inter-fiber bonds are due mainly to: (i) hydrogen bonding between fibers, (ii) the condensation reaction in lignin polymer, (iii) the cross-linking reaction between lignin and

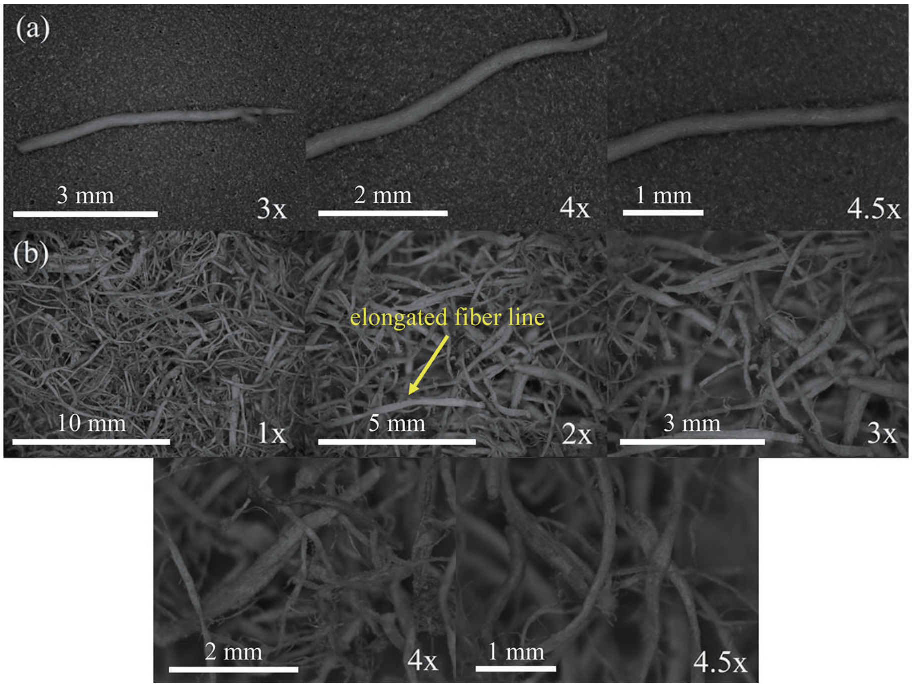

Fig. 2 Microstructure of raw durian fibers (a) single strand, and (b) multiple strands

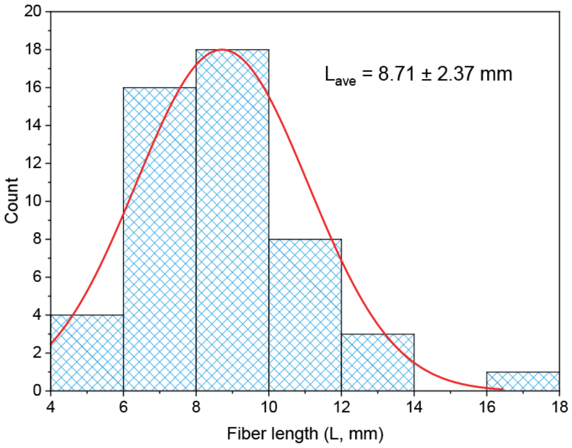

Fig. 3 Distribution of fiber length

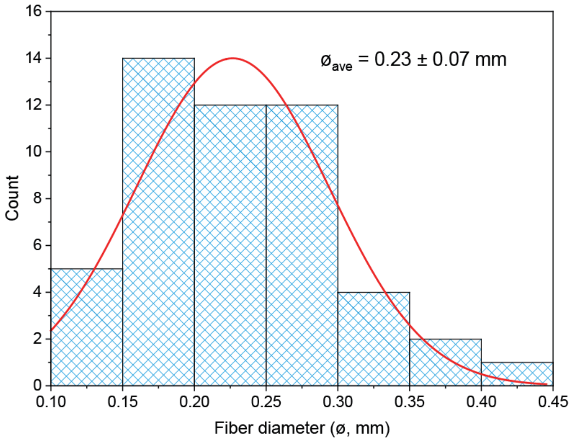

Fig. 4 Distribution of fiber diameter

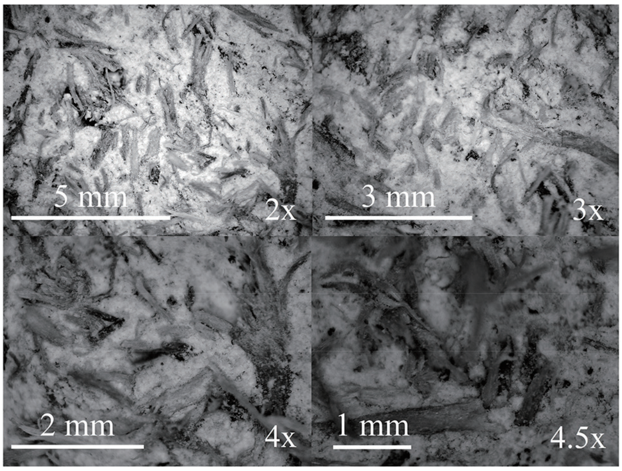

Fig. 5 Microstructure of optimized fiberboard at 640 kPa

polysaccharides, and (iv) the formation of covalent bonds between the constituents of lignocellulosic polymers[22].

3.2 Mechanical properties

3.2.1 Internal Bond (IB)

The IB refers to the bonding strength between fibers which is essential because it ensures that the boards will not delaminate during post-treatment. The internal structure and properties (chemical composition and mechanical properties) of lignocellulosic fibers depend on their (a) place of origin, (b) maturity, (c) species, and (d) extraction methods[20]. In addition, the strength properties of the fibers also depend on test conditions. Since these fibers are lignocellulosic, they behave like viscoelastic materials when subjected to deformation under load.

The effect of press pressure on the IB is presented in Fig. 6. According to ANSI specifications, IB for MDF should be at least 0.6 MPa. Based on the figure, all experimental points tested following the ASTM procedure complied with this requirement. This implies good adhesion between fibers interfaces. Density plays a role in the development of IB value of boards. Increasing density in boards' structure will accommodate a higher IB value[23].

The one-way ANOVA was performed to test the significant difference (Table 2). Eleven trials were conducted per experimental point. An F-value of 3.398 implies that there was a significant difference in the mean IB of the fiberboards (F_{crit}=3.316). Since all the mean IB were within the ANSI specifications and considering that higher IB is an ideal characteristic for MDFs, this implies that the optimal condition was recorded at 760 kPa.

3.2.2 Modulus of Elasticity (MOE)

The mechanical performances of fiberboards are usually expressed by the MOE[24]. The automotive dashboard panels should exhibit Young's modulus of at least 2300 MPa[25]. Furthermore, the product design specification (PDS) values for automotive door panels should exhibit a tensile Young's modulus of at least 1700 MPa[26]. The MOE (Fig. 7) did not follow a linear trend as pressure is increased. At constant ratio of 1:4 and varying press pressure, MOE increased from 520 kPa to 640 kPa but decreased from 640 kPa to 760 kPa. A similar trend was also observed where MOE of all-lignocellulosic fiberboards made from Arundo steam exploded fibers by means of wet process increased from 0.35-12.5 MPa but decreased from 12.5-15 MPa[18]. These results suggested that a high pressing pressure leads to the deterioration of the mechanical performance of fiberboards. According to ANSI specifications, MOE for MDF should be at least 2500 MPa. Based on the figure, only one experimental point (640 kPa) tested following the ASTM procedure complied with this requirement, with an MOE of 3008 MPa, and thus, considered to be the optimal condition.

The one-way ANOVA was performed to test the significant difference of the MOE (Table 3). An F-value of 25.153 implies that there was a significant difference in the mean MOE of the fiberboards (F_{crit}=5.143). This means that only one condition should be considered optimal (640 kPa).

3.3.3 Modulus of Rupture (MOR)

The mechanical performances of fiberboards are also expressed in terms of the MOR[24]. The bending strength of the fiberboards is affected by several factors such as fiber diameters, lumen thickness, and fiber length. In addition to that, it is affected by processing conditions. Interestingly, the strength of fiberboards increased as the pressing pressure was increased from 520 kPa up to 640 kPa, after which this value was decreased while keeping the ratio at 1:4 (Fig. 7). A similar trend was also observed[18], where MOR initially

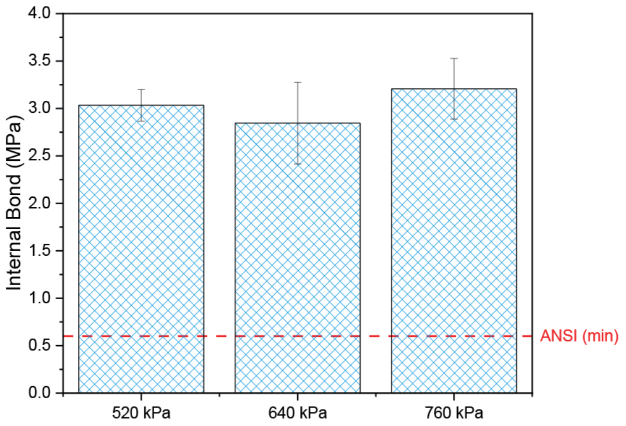

Fig. 6 IB of fiberboard at varying pressure

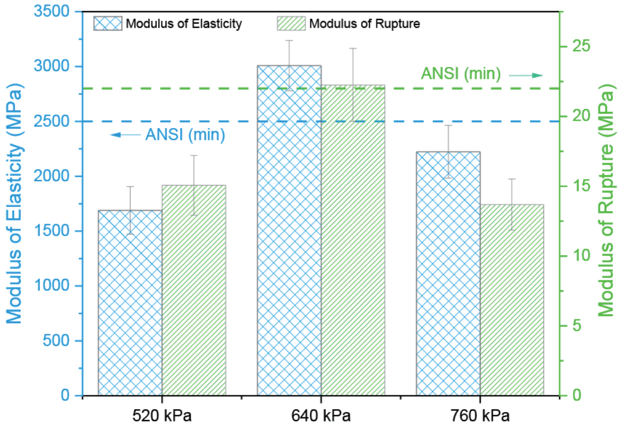

Fig. 7 MOE and MOR of fiberboard at varying pressure

Table 2 One-way ANOVA for IB

Source of Variation	SS*	df$^\wedge$	MS$^+$	F$^\#$	P-value	F_{crit}
Between Groups	0.717	2	0.358	3.398	0.047	3.316
Within Groups	3.163	30	0.105			
Total	3.880	32				

*Sum of Squares; $^\wedge$degrees of freedom; $^+$Mean Sum of Squares; $^\#$F-statistic

Table 3 One-way ANOVA for MOE

Source of Variation	SS	df	MS	F	P-value	F_{crit}
Between Groups	2642431	2	1321215	25.153	0.001	5.143
Within Groups	315157.6	6	52526.27			
Total	2957588	8				

Table 4 One-way ANOVA for MOR

Source of Variation	SS	df	MS	F	P-value	F_{crit}
Between Groups	338.207	2	169.104	34.365	2.38E-07	3.467
Within Groups	103.337	21	4.921			
Total	441.544	23				

increased from 0.35-12.5 MPa but declined from 12.5-15 MPa. These results suggested that a high pressing pressure leads to the deterioration of the mechanical performance of fiberboards.

According to ANSI specifications, MOR for MDF should be at least 22 MPa. Based on the figure, only one experimental point (640 kPa) tested following the ASTM procedure complied with this requirement, with an MOR of 22.25 MPa, and thus, considered to be the optimal condition.

The one-way ANOVA was performed to test the significant difference of MOR (Table 4). An F-value of 34.365 implies that there was a significant difference in the mean MOR of the fiberboards (F_{crit}=3.467). This means that only one condition should be considered optimal (640 kPa).

4. Conclusion

Based on the results, the micrograph of durian rinds fiber showed an elongated fiber line. Durian fiberboard was optimal at a press pressure of 640 kPa, with IB of 2.85 MPa, MOE of 3008 MPa, and MOR of 22.25 MPa. These were compared against properties of commercial MDF based on ANSI specifications (IB≥0.6 MPa, MOE ≥2500 MPa, and MOR≥22 MPa). Generally, boards used as automotive panel should demonstrate lightweight property, high mechanical strength and stiffness. Consequently, application of this optimum durian fiberboard in automotive structural applications results in decrease in weight without compromising structural safety, increase in fuel efficiency and reduction in CO_2 emissions. Hence, it can be concluded that the optimized fiberboard demonstrated high potential for commercial application in the automotive industry.

Acknowledgment

The University of Mindanao funded this study through Dolores P. Torres (DPT) Grant and DOST-PCIEERD through Human Resource Development Program (HRDP) Grant. The study was also made possible by using some of the Center of Green Nanotechnology Innovations for Environmental Solutions (CGNIES) facilities.

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