# Bamboo Waste-based Bio-composite Substance: An application for Low-cost Construction Materials

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**Abstract**

Bamboo is a lightweight and high-strength raw material that encourages researchers to investigate and explore, especially in the field of biocomposite and declared as one of the green-technology on the environment as fully accountable as eco-products. This research was to assess the technical feasibility of making single-layer experimental Medium-Density Particleboard panels from the bamboo waste of a three-year-old (Dendrocalamus asper). Waste materials were performed to produce composite materials using epoxy resin ($C_{21}H_{25}C_{105}$) from a natural treatment by soaking with an average of pH 7.6 level of sea-water. Three different types of MDP produced, i.e., bamboo waste strip MDP (SMDP), bamboo waste chips MDP (CMDP) and bamboo waste mixed strip-chips MDP (MMDP) by following the same process. The experimental panels tested for their physical-mechanical properties according to the procedures defined by ASTM D1037-12. Conclusively, even the present study shows properties of MDP with higher and comparable to other composite materials; further research must be given better attention as potential substitute to be used as hardwood materials, especially in the production, design, and construction usage.

*Keywords:* biocomposite substance, dendrocalamus asper bamboo, green-technology, physical-mechanical properties, traditional preservation

**Abstrak**

*Bambu adalah bahan baku ringan dan berkekuatan tinggi yang menjadi bahan penelitian bagi para peneliti untuk melakukan penyelidikan dan eksplorasi, terutama di bidang biokomposit dan dinyatakan sebagai salah satu teknologi ramah lingkungan di lingkungan yang sepenuhnya menggunakan produk ramah lingkungan. Penelitian ini bertujuan untuk menilai kelayakan teknis percobaan pembuatan panel Medium-Density Particleboard dengan lapisan tunggal dari limbah bambu yang berumur tiga tahun (Dendrocalamus asper). Bahan limbah digunakan untuk menghasilkan bahan komposit menggunakan resin epoksi (C21H25C105) dari pengolahan alami melalui proses perendaman dengan rata-rata tingkat air laut pH 7,6. Tiga jenis MDP yang diproduksi, yaitu, MDP kupasan limbah bambu (SMDP), MDP serpihan limbah bambu (CMDP) dan MDP campuran limbah bambu dengan kupasan serpihan (MMDP) melalui proses yang sama. Panel percobaan diuji berdasarkan sifat fisik-mekaniknya sesuai dengan prosedur yang ditentukan oleh ASTM D1037-12. Melalui penelitian ini, dapat ditunjukkan sifat-sifat MDP dengan bahan komposit lainnya yang lebih tinggi dan sebanding. Pada penelitian selanjutnya, harus dipertimbangkan fungsi MDP sebagai pengganti energi potensial yang dapat dimanfaatkan untuk bahan kayu keras, terutama dalam produksi, desain, dan penggunaan konstruksi.*

*Kata kunci: zat biokomposit, bambu Dendrocalamus Asper, teknologi ramah lingkungan, sifat fisik-mekanik, pelestarian tradisional*

## 1. Introduction

Green-engineering as building construction materials is utilized and explored as our community becomes aware of the harmful consequences associated with industrial production. Sustainable

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construction techniques introduced in the marketplace and green building materials with low embodied energies to minimize the impact on nature. Several works have investigated the mechanical properties of composites reinforced with natural fibres such as bamboo, flax, jute, and hemp (Dauod, 2016).This study, bamboo is a green material that can substitute to wood for reasons that, bamboo can be a crop in 3–4 years from the time of plantation as compared to timber which takes decades (Lakkad and Patel, 1980; Amada et al., 1997). Bamboo utilized as the great potential substitute used as solid wood materials, especially in manufacturing, design, and construction usage. As forest products continue to decrease with the ever increasing demand for wood and wood products, there is a need to innovatively develop bamboo as a substitute to slow growing hardwoods for furniture manufacturing (Anokye, 2015). Due to environmental and ecological concerns, direct production of biopolymers and bio-based composites has driven the development for the past years for their high mechanical performance. Demands for built infrastructure have caused significant waste generation, energy and material consumption by the construction industry. Other common types of construction include farm, school buildings, and bridges. Further applications of bamboo relevant to construction include its use as scaffolding, water piping and as shuttering and reinforcement for concrete (Sharma, 2014). Sustainability in construction materials usage, the construction industry must embrace the reuse of industrial by-products and renewable materials in construction (Onuaguluchi, 2014).

The application of bamboo in construction has been expanded from its conventional way to include variously manufactured composites for structural utilization and as a reinforcement material. Bamboo-based composites in particle form (Rowell and Norimoto, 1988; Chew et al., 1992; Kasim et al., 2001); strand form (Lee et al., 1996; Naresworo and Naoto, 2001); fiber form (Chen at al., 1989; Kumiko et al., 2001; Xu et al., 2001) and combined with cement (Rahim et al., 1996), plastics (Chen et al., 1991), plywood (Chen et al., 1991; Heng et al., 1998), have been measured comprehensively with other composite products. Considering the cellulose fibers which bamboo has, there are many preferences as reinforcement materials for composite compared to artificial fibers. Bamboo is a potential wood replacement, structurally it can be used with a certain limit by the proportionate dimension of the bamboo culm and the low inflexibility of the bamboo (Amatosa et al., 2019), and they come from abundant and renewable resources at low cost (Gatenholm and Felix, 1993), and less-cost significant elements to the plastic industry that provides a continuous fiber allocation (Taib, 1998). Despite the low density, cellulose fibers still lead to composites products with high specific properties even their low strength (Sanadi et al., 1997). (Matsomoto et al., 2001) based on the development of bamboo fiberboard, this shows a precise density profile at any density level. Although the modulus of rupture (MOR) was lower, the modulus of elasticity (MOE) data of the particleboard was about the same as wood fiberboard. The wood fiberboard was lower than the present study for IB strength.

In this present study, particleboard physical and mechanical properties have been undertaken in the manufacturing laboratory to develop less-cost building elements using Dendrocalamus asper bamboo as essential construction materials and it is abundant in the Philippines compared to some other varieties of bamboo. Particleboards physical-mechanical properties depend on the raw material used for manufacturing; however, these properties play a significant role after the manufacturing process when compared with the standards.

## 2. Methods

### *2.1. Materials*

Three-year-old Giant Bamboo *(Dendrocalamus asper)* was harvested from Mandaue City, Province of Cebu in the Philippines. Portions cut up to 3.0 m from the basal part used for the assessment. Bamboo was cut manually and split longitudinally at any position. During the submersion of specimens, 5 for each bamboo part were immersed in salt water to protect bamboo against insect attack for (7) days cycles as traditional preservation. The experimental set up was executed using traditional treatment of the specimens to wetting and drying cycle; the bamboo specimens were removed from the water and were stacked vertically in air-drying for one week (Amatosa and Loretero, 2017).

Table 1: Macroscopic characteristics of Giant bamboo (Dendrocalamus asper)

| **Macroscopic Characteristics** | **Unit** | **Literature** | | | **Native** |
|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **Bamboo *** |
| Culm length | m | 20-30 | 18-23 | - | 20-30 |
| Internode length | cm | 20-25 | 35 | 14-45 | 30-35 |
| Internode Diameter | cm | 8-20 | 9-13 | 1.2-9.3 | 8-18 |
| Culm wall Thickness | mm | 11-20 | 10-14 | 4-30 | 6-13 |

*Source: ([1]Dransfield and Widjaja, 1995; [2]Othman et al., 1995; [3]Pakhkeree, 1997) *Present study*

### *2.2. Methods*

Wastage such as the front and back face of bamboo fiber was chipped and stripped. An opening mesh by 5mm was utilized to eliminate undersized and oversized particles. Varying containers were used for the separation of chips and strip particles. An oven was used for heat application of the particles for over 24 hours with 103±2ºC temperature to measure moisture. Epoxy resin ($C_{21}H_{25}ClO_5$) with 48% solid content was used as a binder in creating the boards to the desired proportions. The manufactured particleboards are of three types: bamboo waste strip particleboard (BWSP), bamboo waste chips particleboard (BWCP), and bamboo waste mixed strip-chips particleboard (BWMP) with 1:1 ratio ideally on the dimensions of 30 cm by 30 cm with 20 mm thickness. In the creation of the mold for the particleboards (PB), excess plyboard from the machine shop was utilized, cut with the jigsaw hammer to create specific borders. Manual formation of the mats was done, and compression occurred in the attempt to obtain the ideal dimensions and to increase the mechanical properties as well. The dimensions of the PBs were measured using a ruler, a Vernier caliper and a micrometer caliper. The weights of the PBs were measured using a triple balance beam which was done before and after heating in the oven. During testing, in the water absorption (WA) and Thickness Swelling (TS) test, another clean and separate container was used and poured in several specimens that soaked at room temperature for 24 hours. For the tensile and bending tests, the universal testing machine was used. The experimental panels tested for their physical-mechanical properties according to the procedures defined by ASTM D1037-12 (ASTM, 2012).

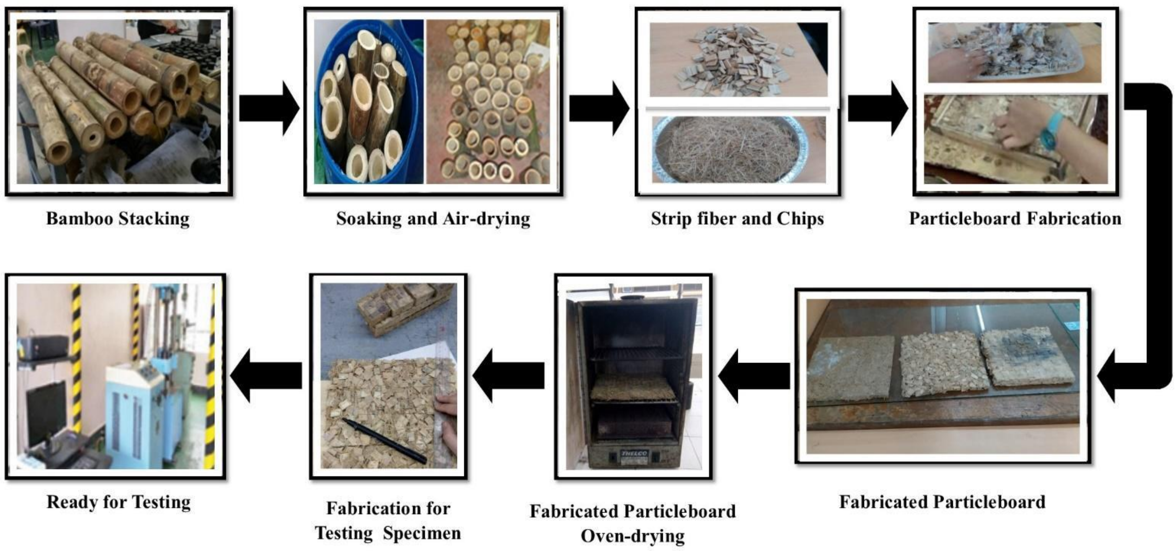


Figure 1: Distribution Flow of Manufactured Bamboo Waste Particleboard

## 3. Result and discussion

This paper analyses the waste of a treated giant bamboo species within one week and air-dried for another week, if it could influence the mechanical properties of the specimen, specifically compressive and bending strength together with the other properties of the laminated composite.

### *3.1. Density*

Noted that the difference in raw material and impregnation ratio is making some effect on the board density. All Particle Boards should be medium density boards (37-50 lb/cubic ft) that are a commercial standard. Board density is having much impact on properties like MOR, MOE, IB, TS, and WA, etc. The density is calculated by dividing the weight by the volume of each specimen, given by the formula below:

$$Density = \frac{W_a W_a}{V_a V_a} \quad (1)$$

where $W_a$ is the air-dried weight, and $V_a$ is the air-dried volume. The results are sighted in Table 2 and comparisons can be made that with different methods of manufacturing the particleboards, different values of the density were calculated varying from approximately 37.8 to 42.6 pounds per cubic feet.

### *3.2. Moisture Content (M. C.)*

Equilibrium moisture content for the Particleboard was 8%, and the average moisture content of all boards was 8.12% basing from Table 3. Equilibrium moisture content mainly depends on relative humidity. Particle Boards should be conditioned to reach equilibrium with the humidity level in which it is to use. Measurement of moisture content can be achieved by weighing or by using an electric moisture meter. Linear dimensions and thickness change if there is a change in moisture content; therefore, it is a significant property to be calculated to estimate adjustments during material usage. M.C. is calculated using the formula below:

$$M.C.\% = \frac{W_a - W_o W_a - W_o}{W_o W_o} \text{ x } 100\% \text{ x } 100\% \quad (2)$$

where $W_a$ is the air-dried weight, and $W_o$ is the Oven dried weight of the particle board. From the results in Table 3, the moisture content values of the three types of particleboards were accurate with one another.

### *3.3. Water Absorption Test (W. A.)*

From former studies, the effect of water on the properties like bending strength and bending stiffness is very severe. There is a chance of strength reduction of boards because of the water. So, water absorption is a fundamental property for any Particle Board. Based on the observations after the specimens taken from the bath, a developed whitish layer was the most evident change among the three specimens which was the effect of the wood glue used as a binder. The formula used for calculating the W.A. is:

$$W.A.\% = \frac{W_f - W_i W_f - W_i}{W_i W_i} \text{ x } 100\% \text{ x } 100\% \quad (3)$$

where $W_f$ is the final weight and $W_i$ is the initial weight depicted in Table 3.

### *3.4. Thickness Swelling (T. S.)*

Specimens with dimensions of 50 mm x 50 mm were prepared for evaluation of the thickness swelling. The effects of thickness swelling in the Particle boards are because of the moisture and absorption properties. Thickness swelling should not be more than 2-3%. Thickness swelling is very much lower after drying. The change in thickness is an important aspect when it comes to real-life applications of the material in predicting adjustments to prevent failure. The formula used for calculating the T.S. is:

$$T.S.\% = \frac{T_f - T_i T_f - T_i}{T_i T_i} \text{ x } 100\% \text{ x } 100\% \quad (4)$$

where $T_i$ is initial thickness, and $T_f$ is final thickness depicted in Table 2.

Table 2: Physical properties of bamboo waste particleboard

| **Particleboard** | **Thickness** | **Density** | | **MC** | | **WA** | | **TS** | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | IW | FW | IW | FW | IT | FT |
| | (mm) | (lb./ft$^3$) | (kg/m$^3$) | % | | % | | % | |
| Strip | 17.20 | 42.57 | 681.91 | 8.13 | | 59.70 | | 2.53 | |
| | | | | 0.7145 | 0.6616 | 19.85 | 31.70 | 16.50 | 17.00 |
| Chips | 19.10 | 47.50 | 760.88 | 8.37 | | 50.94 | | 2.19 | |
| | | | | 0.8705 | 0.8033 | 21.20 | 32.00 | 19.10 | 19.50 |
| Mixed | 19.50 | 37.80 | 605.50 | 7.85 | | 72.29 | | 3.11 | |
| | | | | 0.7043 | 0.6530 | 16.60 | 28.60 | 19.30 | 19.90 |
| Standards | | | | | | | | | |
| IS 3129 – 1985 | 6-40 | 500-900 | | - | | 50 | | - | |
| DIN 68761 | 13-20 | | 600-750 | | - | | - | - | |
| BS EN 312 – 7 | 6-19 | Medium density | | - | | - | - | | |
| AS / NZS 1859.1 | 13-22 | | 660-680 | | - | | - | 12.00 | |

*MC-Moisture Content, WA-Water Absorption, TS-Thickness Swelling*

### *3.5. Tensile Strength or Internal Bond Strength*

Using three (3) treated samples of 50 mm x 50 mm from each particleboard, tensile strength perpendicular to the grain was determined. Internal bond strength is commonly examined the property for any Particle Boards. Regarding strength properties, this is one of the properties which have much significance. To find the materials maximum load that can be applied before it tears, it is the mechanical test performed on the laboratory. The sample was placed on the machine and anchored at both ends. While the machine pumped manually, both tensioned ends stretched till it failed. The failure occurred was through splitting. The test was calculated using the formula:

$$ƶtƶt = \frac{W\,(load\ in\ N) W(load\ in\ N)}{Area\ (mm^2)\ Area\ (mm^2)} \quad (5)$$

The area refers to the cross-sectional area of each specimen which is calculated by multiplying the base by the respective thickness. As per standards for ultimate tensile strength, this varies from 1.9 to 11.4 kN per mm squared. The highest averaging values were the values of the Fiber PB, and the least was from the manufactured Chip PB.

### *3.6. Bending Stiffness (MOE)*

Load-deflection curves according to the following formula below where used for the computation of Modulus of Elasticity (MOE) for bending and Modulus of Rupture (MOR). Measurement of stiffness or resistance to bending stress is applied where Modulus of Elasticity is an essential property.

$$MOE = \frac{P_{bp} \mathrm{x} L^3\ P_{bp} \mathrm{x} L^3}{4bh^3(Y_p)\ 4bh^3(Y_p)} \quad (6)$$

where $P_{bp}$ is the load at the proportionality limit, $L$ is the Span length in $mm$, $b$ is the width of the specimen in $mm$, $h$ is the thickness of the specimen in $mm$, and $Y_p$ is the deflection corresponding to $P_{bp}$ $(mm)$.

### *3.7. Bending Strength (MOR)*

Modulus of rupture is an important property determining the application of the product for structural components. These results depend according to the board density. A three-point bending test applied for this properties. Load-deflection curves for MOR can be computed using this equation.

$$MOR = \frac{3P_bL\ 3P_bL}{2bh^2\ 2bh^2} \tag{7}$$

where, $P_b$ is the maximum load, $L$ is the span length in $mm$, $b$ is the width of the specimen in $mm$, and $h$ is the thickness of the specimen in $mm$. According to (Chithambaram et al., 2014), using micro fibrillated cellulose has attracted much attention as mechanical performance enhancer in polymers and composites due to environmental concern.

Table 3: Mechanical properties of bamboo waste particleboard

| **Particleboard** | **Specimen** | **Internal Bond Strength (UTS)** | | **Bending Stiffness (MOE)** | | **Bending Strength (MOR)** | |
|---|---|---|---|---|---|---|---|
| | | (MPa) | Mean | (MPa) | Mean | (MPa) | Mean |
| Strip | | | | | | | |
| | 1 | 0.385 | | 2560.32 | | 14.88 | |
| | 2 | 0.492 | | 2369.57 | | 15.16 | |
| | 3 | 0.414 | 0.424 [(10)a] | 2409.67 | 2474.50 [(3)] | 14.60 | 14.848 [(1)] |
| | 4 | 0.390 | | 2572.50 | | 14.90 | |
| | 5 | 0.440 | | 2460.43 | | 14.70 | |
| Chips | | | | | | | |
| | 1 | 0.471 | | 2566.06 | | 16.00 | |
| | 2 | 0.574 | | 2642.88 | | 17.47 | |
| | 3 | 0.485 | 0.482 [(12)] | 2620.50 | 2550.087 [(3)] | 15.10 | 15.628 [(7)] |
| | 4 | 0.458 | | 2490.45 | | 14.52 | |
| | 5 | 0.422 | | 2430.60 | | 15.32 | |
| Mixed | | | | | | | |
| | 1 | 0.804 | | 2683.35 | | 19.65 | |
| | 2 | 0.976 | | 2844.80 | | 20.42 | |
| | 3 | 0.942 | 0.852 [(12)] | 2786.55 | 2722.73 [(3)] | 20.30 | 19.19 [(7)] |
| | 4 | 0.755 | | 2643.75 | | 17.60 | |
| | 5 | 0.785 | | 2655.20 | | 18.00 | |
| Standards | | | | | | | |
| IS 3087, 1985 | | 0.80 | | - | | 11.20 | |
| DIN 68761 | | 0.35 | | - | | 18.00 | |
| BS EN 312 – 7 | | 0.35 | | - | | 15.00 | |
| AS / NZS 1859.1 | | 0.45 | | 2600.00 | | 15.00 | |

[a] *Values in parenthesis are coefficients of variance*

## 4. Conclusion

Many advantages of using wood-based Particleboard as sustainable alternative materials with numerous similarities between the composition, application and creation process. When it comes to quality concerned, similarities are difficult to recognize the differences. These factors have significant effects on their mechanical properties. From this study, it concluded that the new development in innovation from bamboo waste to biocomposites need to be more highlighted. The critical problem in the next generation is the biodegradability and recyclability of design based material. In addition to the increase in population, the regulation forced the manufacturer to use natural fiber in further products. As we all know, that the design, manufacturing, and applications for this product are up for a low cost, environmentally friendly, accessible and easy production of natural fiber biocomposite. Conclusively, growing interest worldwide in the event of bamboo products as a sustainable, cost-

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effective and ecologically responsible alternative construction material, similar to medium-density particleboard from bamboo waste could use for production. Also, bamboo particleboard compared to wood fiberboard showed lower water absorption and thickness swelling.

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