Feasibility of using low resin content levels in the production of bamboo particle composite: basic properties

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Abstract. In this study, the suitability of Semantan bamboo (Gigantochloa scortechinii) particles in the production of single-layered composite board was investigated. The effects of different resin types and low resin content levels on the basic properties (mechanical and physical properties) of particle composite board made from G. scortechinii were determined. The 12-mm thickness boards with dimension of 340 × 340 mm and targeted density of 660 kg/m³ were fabricated. Types of resin used were melamine urea formaldehyde (MUF) and urea formaldehyde (UF), while resin content levels were 3.5 and 5%. In general, the mechanical and physical properties of board blended with MUF resin were better than UF due to the presence of melamine in MUF that influenced the properties. Board made from 5% resin content were better in term of mechanical and physical properties than 3.5% resin content levels. 5% resin content level had increased the particles bonding ability, thus influenced the excellent properties of the board. However, in general, the properties of bamboo particle composite board in this study were not comparable to the board made from wood. Only IB properties of bamboo particle composite board exceeded the minimum requirements as stipulated in standards. As a consequence, the information of particle composite board made from bamboo is important in assessing bamboo’s usefulness as an alternative raw material for wood-based industries. The final results obtained could be used as reference for researchers and manufacturers.

1. Introduction

The growing demand of wood-based panels has led to continuous efforts to find new resources as alternative raw materials in place of wood. In order to solve this problem, Malaysia still has non-wood resources which are not fully utilized. One of such resources is bamboo. Semantan bamboo (Gigantochloa scortechinii) was used in this study because of its wide availability in Malaysia. Bamboo grows faster than the forest tree and can be harvested within 3 to 5 years [1], versus to 10 to 100 years for most softwoods and hardwoods. The literature review on bamboo-based composite board was also reported in this study. The current article dataset was collected from Scopus database. The central theme in this study was research articles containing “bamboo” and “particleboard” in the title, abstract and keywords. This paper chose the following combinations of queries to track all related articles: TITLE-ABS-KEY (“bamboo”) AND TITLE-ABS-KEY (“particleboard”) AND TITLE-ABS-KEY (“urea...
formaldehyde” OR “melamine-urea formaldehyde”) AND PUBYEAR < 2021 OR PUBDATETXT ("january 2021" OR "february 2021" OR "march 2021" OR "april 2021" OR "may 2021" OR "june 2021" OR “july 2021” OR “august 2021")). This query string resulted in 18 documents with the oldest publication dates to 2002 (Table 1).

| Authors          | Cited by | Description                                                                                     |
|------------------|----------|-------------------------------------------------------------------------------------------------|
| Biswas et al.    | 40       | Investigated two locally grown bamboo species of Bangladesh. The panels were tested to determine bending strength, modulus of elasticity, tensile strength, thickness swelling and water absorption. The variation in particle geometry of the raw materials has significantly influenced the physical and mechanical properties of particleboard. |
| Arruda et al.    | 23       | Evaluated the utilization of the recently identified Brazilian giant bamboo, *Guadua magna* to manufacture medium density particleboard. Mechanical, physical and non-destructive properties of the panels were assessed. The particleboards produced with PF showed better dimensional stability than UF particleboards. The addition of wood particles improved the mechanical properties of the board. |
| Iswanto et al.   | 17       | Evaluated physical, mechanical and durability properties of sorghum bagasse-particleboard (SBP) which was layered by several materials. The results showed that surface layer treatment improved the bending properties presented by increasing of modulus of rupture and modulus of elasticity value of surface layer treatment of SBP compared to untreated ones. |
| Yang et al.      | 14       | Developed a novel bamboo product with a corrugated structure, from bamboo waste (planer waste). The results showed that the performance of composite is highly dependent upon the board density. |
| Stangerlin et al.| 11       | Evaluated the natural resistance of wood panels made of particles of wood (*Eucalyptus grandis*) and/or bamboo (*Bambusa vulgaris*) to decay fungi. It was observed that panels which were made with a mixture of particles of wood and bamboo were less resistant to attack by decay fungi. |
| Valarelli et al. | 10       | Evaluated the physical and mechanical characteristics of particleboard made of bamboo waste from *Dendrocalamus giganteus* bonded with two different types of adhesives: urea-formaldehyde (UF) and a castor oil-based adhesive. Particleboards produced with UF particleboards showed superior results for both physical and mechanical characteristics, when compared to castor oil based adhesives particleboards with the same percentage of adhesive. |
| Zhang et al.     | 8        | Phenol formaldehyde reaction solution (PFS) was used to synthesize urea-formaldehyde resins (PFSUF resins) with low formaldehyde content. The results show that bamboo particleboards bonded with PFSUF resins exhibit better mechanical properties, water resistance, and dimensional stability than that bonded with pure UF resin. |
| Laemlaksakul    | 6        | Evaluated a technical feasibility of making single-layer experimental particleboard panels from bamboo waste (*Dendrocalamus asper*) by converting bamboo into strips, which are used to make laminated bamboo furniture. The test result of mechanical properties showed that the modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding (IB) values were not in the set criteria. |
| Brito and Bortoletto | 3     | Addresses an evaluation of the physical and mechanical properties of particleboards manufactured from bamboo particles (*Dendrocalamus asper*). The panels made of treated particles showed higher density profile values in both layers of the panels. The granulometry did not influence the mechanical properties of the panels, and those with treated particles exhibited significant performance for the surface and top screw withdrawal properties, and internal adhesion. |
| Teodoro et al.   | 3        | Evaluated the impact of using different contents of bamboo particles in the particleboard core, on their physical and mechanical properties. There was no |
In addition, resin types and resin content levels are very important in controlling the mechanical and physical properties of any particle-based composite board products. This study was conducted to determine the significant effect of different resin contents levels in the properties of particle composite board. Two types of resins that are widely used by the manufacturer in the production of particle-based composite board are urea formaldehyde (UF) and melamine-urea formaldehyde (MUF). This study therefore resorted to the use of MUF and UF since they are widely used and available.

With this rationale, characterization on mechanical and physical properties of bamboo particle composite board made from G. scortechinii was conducted with the following objectives: (1) to characterize the effects of different resin types on mechanical and physical properties of the board, (2) to characterize the effect of different resin content levels on the mechanical and physical properties of the board.

2. Materials and methods
2.1. Materials

2.1.1. Bamboo particles. The bamboo culms were selected from Bio-Composites Technology Laboratory, Faculty of Applied Sciences, UiTM Shah Alam, Malaysia. Each bamboo culm was then crushed using hammer mill machine to produce bamboo particles. The particles were then screened using vibration screening machine into several particle sizes. Acceptance particle sizes were between 1 and 3 mm. Then, the screened particles were dried to 5% moisture content (MC) in oven drier for one week.

2.1.2. Resins. Two types of resin were used in this study, namely urea formaldehyde (UF) and melamine-urea formaldehyde (MUF). The resins were supplied by local resin company, Malayan Adhesives and Chemicals (MAC) Sdn. Bhd., located in Shah Alam, Malaysia, and was formulated according to commercial uses. In the particleboard manufacture, two different resin content levels (3.5 and 5%) were applied. The hardener used was ammonium chloride (NH4Cl) solution with a concentration of 20%. The amount of hardener added was equivalent to 2% of the weight of the resin solution used.

2.2. Methods

2.2.1. The fabrication of bamboo particle composite board: particle-resins mixing and hot pressing

Medium density particleboard which is range from 0.590 g/cm³ to 0.800 g/cm³ are normally graded in composition along their cross-section, using low-size particles and high concentration of adhesive on the particleboard surface (leading to improved physical and mechanical properties), and high-size particles in the particleboard core (interior), which provide higher porosity [11].

The target board density in this study was 660 kg/m³. For the first step of particleboard manufacture, the particles were placed in the glue mixer and sprayed with a resin mixture. The resin mixture was sprayed as a fine mist at an air pressure of 0.4 MPa to obtain an even distribution of resin over bamboo particle. After the completion of spraying process, the particles were then manually formed as a matt in a wooden mould with a dimension of 340 mm x 340 mm. The formed particles were pre-pressed at 1000 psi for about two minutes. The wooden mould then was removed and two metal stoppers of 12 mm thickness were placed at both sides of the matt before another stainless-steel plate was laid on the top of pre-pressed board.

The pre-pressed board was then finally hot pressed to the required thickness of 12 mm for six minutes with three phases. For the first phase, the pressure applied was 130 kg/m² for three minutes. For the second phase, the pressure applied was 80 kg/m² for two minutes. The pressure of 50 kg/m² for one minute was applied in the last phase. After the hot press process, the particleboard was then cooled under room temperature.

Three particleboards were produced for each parameter. A total number of 12 particleboards were produced in this study. The particle-based composite boards were trimmed into size of 340 mm x 340 mm. Then, the boards were left in a conditioning chamber for approximately two weeks with a relative humidity of 65 ± 5% and a temperature of 20 ± 2ºC as required by the British Standard BS EN 310:1993 [20]. After the completion of conditioning process, the boards were cut into specific sizes for mechanical and physical testing.

2.2.2. Determination of basic properties of the board: mechanical and physical properties

The modulus of elasticity (MOE) and modulus of rupture (MOR) in bending were determined in accordance with the BS EN 310:1993 [20]. The samples were cut in rectangular shape with dimension of 50 mm in width using radial arm saw. The length was 20 times the nominal thickness with additional length of 50 mm. The span length is 20 times the nominal thickness. The mechanical tests were conducted using Instron Universal Testing Machine. The samples were placed on the supports with the centre point under load. The load was applied at a constant rate of 5 mm/min and tested until its reached failure. The MOE and MOR values were calculated and recorded.
The internal bonding (IB) test was conducted in accordance to BS EN 319:1993 [21]. The test blocks used were solid stainless steel to which the samples were glued. The test samples were cut square with a side length 50 x 50 mm using radial arm saw. Each specimen was firstly lightly sanded to remove contaminated materials at the surface. The samples were bonded to the test block using hot-melt glue. The glued samples were stored in a conditioning chamber under controlled condition of 65 ± 5% relative humidity and at temperature of 20 ± 2°C for 24 hours. After conditioning process was completed, the samples were tested using Instron Universal Testing Machine for IB test. The crosshead movement was at a constant rate of 3 mm/min. Then, the IB was calculated using Equation 1.

\[ IB = \frac{F_{\text{max}}}{a \times b} \]  

Where:
- \( IB \) = tensile strength perpendicular to the plane of the test piece (N/mm²)
- \( F_{\text{max}} \) = breaking load (N)
- \( a, b \) = length and the width of the test piece (mm).

For physical properties, the test conducted were thickness swelling (TS) and water absorption (WA). The determinations of thickness swelling (TS) and water absorption (WA) values were conducted according to BS EN 317:1993 [22]. The size of the samples was 50 x 50 mm. The thicknesses of samples were measured using digital calliper before and after immersion in water, while the weights of samples were measured using digital electronic balance before and after immersion in water. The samples were immersed in water bath at a temperature of 20 ± 1 ºC. The TS and WA values were calculated and recorded. Table 2 shows the samples size and number of samples for each testing.

| Property                  | Samples’ Size (mm) | No. of samples per board |
|---------------------------|--------------------|--------------------------|
| MOE and MOR in Bending    | 290 x 50 mm        | 4                        |
| IB, TS and WA             | 50 x 50 mm         | 5                        |

Note: MOE = Modulus of elasticity, MOR = Modulus of rupture, IB = Internal bonding, TS = Thickness swelling, WA = Water absorption

2.2.3. Data Analysis. Statistical Package for Social Science (SPSS) analysis software was used in data analysis. Analysis of Variance (ANOVA) and t-test were used to analyze the data collected and to determine the significant effect of different resin types and resin content levels. All results were compared to the mean values as stated in the British Standard (BS) [20 – 22].

2.2.4. Experimental Design. Figure 1 illustrated the experimental design of this study. Three particle composite boards were produced for each parameter. A total number of fifty-seven (57) samples were produced for all tests.
Figure 1. The experimental design of this study

3. Results and discussion

Table 3 shows results for the average mechanical and physical properties of the boards for each different resin types and resin content levels. Boards made from MUF5% exhibited the highest MOE value (1830.82 N/mm²). The lowest value was UF3.5% (1455.43 N/mm²). There is a difference between UF5% and MUF5%, between MUF3.5% and MUF5%, and between UF3.5% and MUF5%. However, all tested samples did not meet the minimum requirement of BS EN 310: 1993 (2000 N/mm²) [20]. Resin types has influenced the MOE values of the board. The presence of melamine in MUF had effect on the MOE values of the boards. The MOE improved with the increment of resin content levels. This result is similar to Jamaludin [23]. Kelly [24] also stated that MOE values increased with increasing board density, surface density and adhesive content. Higher resin content means more bonding surfaces, thus improving the MOE of particle composite boards.

Next is the comparisons of MOR mean values between resin types and between resin content levels. Board made from MUF5% are observed to possess the highest MOR value (16.1917 N/mm²). The lowest MOR value is UF3.5% (9.5117 N/mm²). The MOR values are significantly different between UF5% and MUF5%, between MUF3.5% and MUF5%, as well as between UF3.5% and MUF5%. Yet, all the tested samples did not meet the minimum requirement of BS EN 310: 1993 (28 N/mm²) [20].

The following test is for the comparison of IB mean values. Board made from MUF5% exhibits the highest IB values (0.72 N/mm²) and has surpassed the minimum requirements of BS EN 319: 1993 (0.60 N/mm²) [21]. Overall, the IB results for MUF5% board are significant with UF5% and UF3.5%.

The results of the physical properties of particleboards were calculated for TS and WA. Board made from MUF resin exhibited lower TS values compared to UF at the same resin content level. The presence of melamine in MUF has increased the resistance of the board to absorb water. High resin content level has reduced the TS value due to more surface of particles were covered by resin, thus reducing the thickness swelling and increasing the dimensional stability. However, all tested samples have not met the minimum requirement of BS EN 317: 1993 (8%) [22]. The physical properties of panels decreased with increasing proportion of bamboo particles in the core of the board panels [11]. Then the comparison of WA mean values shows that the board made from MUF resin exhibited lower WA values compared to UF. Board made from higher resin content level influenced the lower WA mean values. Higher resin
content levels had affected the lower WA values due to high bonding ability of particles and resin thus hinder the penetration of water.

| Testing | Minimum Requirement (British Standard) | UF 3.5% | UF 5% | MUF 3.5% | MUF 5% | Findings |
|---------|---------------------------------------|---------|-------|----------|-------|----------|
| MOE (N/mm²) | BS EN 310: 1993 [20] | 1455.4 | 1500.1 | 1462.6 | 1830.82 | All parameters did not meet the minimum requirement of standard |
| MOR (N/mm²) | BS EN 310: 1993 [20] | 9.51 | 11.44 | 10.87 | 16.19 | All parameters did not meet the minimum requirement of standard |
| IB (N/mm²) | BS EN 319: 1993 [21] | 0.46 | 0.56 | 0.44 | 0.72 | Only sample from MUF with 5% resin content level meet the minimum requirement of standard |
| TS (%) | BS EN 317: 1993 [22] | 28.91 | 20.35 | 26.63 | 19.83 | All parameters did not meet the minimum requirement of standard |
| WA (%) | - | 97.83 | 82.31 | 98.29 | 78.48 | - |

4. Integrative discussion
Based on the results, there is no solid outcome to justify that the properties of *G. scortechinii* particle composite board were comparable to particleboards made from wood or agricultural residues. Therefore, we provide extensive discussion by comparing research findings that used bamboo particles as the main components for the particleboard testing (Table 4). The thickness and target density of the panels for all researchers was 12 mm to 13 mm and 0.65 g/cm³ respectively. Only boards produced by Teodoro et al. [11] had 15.7 mm thickness with 0.70 g/cm³ density.

The study conducted by Valarelli et al. [7], Valarelli et al. [12] and Arruda et al. [3], that produced 100% bamboo composite board. Valarelli et al. [12] produced particleboards using UF adhesive in four different proportions which are 6%, 8%, 10% and 12%. Particleboard produced with 12% adhesive proportions was selected for comparison because it had better MOE, MOR and thickness swelling. Based on the findings, the boards met the standard requirements for only IB and WA. None of the treatments studied met the minimum requirement of the British Standard for the MOE and MOR. This finding was expected because the higher amount of adhesive applied to the mix promotes better water proofing of the surfaces and reduces the water absorption rate [13].

Valarelli et al. [7] tested eight types of particleboards in the proportions of 6%, 8%, 10% and 12% using two different types of adhesives: urea-formaldehyde (UF) and a castor oil-based adhesive. Similar to the previous study, comparison was done with boards made with 12% of UF and castor oil adhesive. All basic properties did not meet the minimum standard requirement, except for the TS.

Arruda et al. [3] tested particleboards made from 100% bamboo particles and bonded with UF and PF resin. It was expected that the boards produced with PF would present better mechanical properties since the resin generally produces stronger bonds than melamine and urea-based resins. Though the PF boards had better dimensional stability compared to the UF bonded boards, all basic properties did not meet the minimum standard requirements.

Research done with a combination of bamboo and agricultural residues were also studied. Brito and Bortolotto [13] used non-wood materials which are 75% bamboo and 25% sugarcane bagasse. Results obtained did not meet the minimum standard requirements. In general, the addition of bamboo particles in the core of the panels, improved physical properties (water absorption and thickness swelling), because of decreasing porosity of the panels.
Particleboards produced from a combination of bamboo and wood particles were also reported. Teodoro et al. [11] suggested to produce MDP (medium density particleboard) with a density of 0.590 to 0.800 g/cm³ and a percentage distribution of 20/60/20 (face/core/face). According to the authors, there was a decrease in the values of water absorption and thickness swelling, with increase in bamboo particles in the core of the panels. However, only IB results did meet the minimum standard requirements. Therefore, addition of large amount of wood particles in the bamboo boards were suggested to improve the mechanical properties, while other properties should be improved as well.

### Table 4. Contemporary literature on the value of basic properties of composite board from bamboo

| Author                  | Materials                                                | Adhesive | MOE (N/mm²) | MOR (N/mm²) | IB (N/mm²) | TS* (%) | WA* (%) |
|-------------------------|----------------------------------------------------------|----------|-------------|-------------|------------|---------|---------|
| BS standard             |                                                          |          | 2000        | 28          | 0.60       | 8       | -       |
| Current study           | 100% bamboo                                              | UF3.5%   | 1455.4      | 9.51        | 0.46       | 28.91   | 97.83   |
|                         |                                                          | UF5%     | 1500.1      | 11.44       | 0.56       | 20.35   | 82.31   |
|                         |                                                          | MUF3.5%  | 1462.6      | 10.87       | 0.44       | 26.63   | 98.29   |
|                         |                                                          | MUF5%    | 1830.8      | 16.19       | 0.72       | 19.83   | 78.48   |
| Brito and Bortoletto    | 75% bamboo and 25% sugarcane bagasse                     | UF       | 772         | 5.06        | 0.23       | 10.35   | 63.79   |
| Teodoro et al. [11]     | Face and back: Pinus wood Core: 100% bamboo              | UF       | 1636        | 13.9        | 0.66       | 17      | 73      |
| Valarelli et al. [12]   | 100% bamboo                                              | UF       | 1682        | 8.55        | 1.36       | 5.63    | 52.93   |
| Valarelli et al. [7]    | 100% bamboo                                              | UF       | 1750        | 9.86        | -          | 7.82    | 43.73   |
| Valarelli et al. [7]    | 100% bamboo                                              | Castor oil-based | 757 | 5.64        | -          | 8.17    | 63.73   |
| Arruda et al. [3]       | 100% bamboo                                              | UF       | 1819        | 13.44       | 0.32       | 21.86   | 77.19   |
| Arruda et al. [3]       | 100% bamboo                                              | PF       | 1722        | 13.60       | 0.26       | 18.20   | 81.77   |

Note: *After 24 hours

### 5. Conclusions

In general, the finding from the mechanical and physical tests found that the bamboo particle composite board made from melamine urea formaldehyde (MUF) resin were better than those made with urea formaldehyde (UF) due to the presence of melamine in MUF that influenced the properties. Boards made from higher resin content were better in term of mechanical and physical properties than those with lower resin content levels. The higher resin content level had increased the particles bonding ability thus influencing the improved properties of the board. However, results obtained for all tests did not meet the minimum requirements of the British Standard (BS EN 310: 1993, BS EN 317: 1993 and BS EN 319: 1993) [20 – 22], except for IB properties for boards bonded with MUF at 5% resin content level.

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