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PHYSICAL AND MECHANICAL PROPERTIES OF GLUED LAMINATED BAMBOO LUMBER

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Glued laminated bamboo lumber (GLBL) made of *Dendrocalamus asper, Dendrocalamus giganteus, Dendrocalamus latiflorus* and *Gigantochloa levis* has potential to overcome the shortage of wood supply. The objective of the study was to determine the effects of bamboo species on the properties of GLBL. Laboratory-scale GLBL was manufactured from 26–28 bamboo strips from each bamboo species, assembled vertically, glued with 250 g m^{-2} of water-based polymer-isocyanate, and applied force horizontally on the wooden clamps at room temperature for one hour. The dimensions of GLBL was 60 cm × 16 cm × thickness. Statistical analysis revealed that bamboo species significantly influenced the properties of GLBL. It was recorded that *D. asper* had superior physical and mechanical properties compared to other bamboo species in this study. The mechanical properties of *D. asper* GLBL were corresponding to wood strength class I, while GLBL made of *D. giganteus*, *D. latiflorus* and *G. levis* had equivalent strength to wood strength class II. The findings in this study affirmed that GLBL made of four bamboo species are promising materials for furniture and building components.

Keywords: Bamboo species, isocyanate, laminated bamboo lumber, physical and mechanical properties

INTRODUCTION

Decreasing resource availability and increasing resource demands in today's modern industrialised world lead to explore opportunities for new, sustainable building materials (Meadows et al. 1992). To date, there is a discrepancy between supply and demand of good quality wood for furniture and building materials in Indonesia. Therefore, the search for material as substitute or complement to wood is an urgent concern. However, the shape and dimensions of bamboo appear to limit its usage as wood substitute or complement to wood. The circular and hollow shape of bamboo must be converted into a flat and relatively thick material, so that it becomes more flexible in its application. Producing bamboo composite such as glued laminated bamboo lumber (GLBL) from bamboo strips by the aid of appropriate adhesives is one way to overcome the problem. There are some comparable properties of laminated bamboo to those of wood such as the strength and stiffness, making bamboo capable of replacing wood in structural applications for load-carrying (Mahdavi et al. 2011). Moreover, bamboo is far better than structural steel, aluminum alloy, cast iron, timber and concrete, showing that it has a very efficient load-bearing capability. Furthermore, it is stated that the use of bamboo could be better in economical, environmental and perhaps, structural benefits (Mahdavi et al. 2011, Ni et al. 2016).

There are several factors affecting the quality of glue laminated bamboo, in particular the type of resin, glue spreading level or the quantity of adhesive and mechanical parameters such as pressure unit and the type of joint (Zhou et al. 2016, Ogunsanwo et al. 2019). The application of phenol formaldehyde (PF) with double-sided adhesive (250 g m^{-2}) showed the best performance in terms of mechanical properties of laminated bamboo for structural purposes (Zhou et al. 2016). Meanwhile, Ogunsanwo et al. (2019) used polyvinyl acetate (PVAc) resin and recommended adhesive level of 200 g m^{-2} for best mechanical properties. Studies on the properties of GLBL, using different bamboo species, are still limited. Glued laminated bamboo is defined as a structural bonding of bamboo strips with essentially parallel grains (ISO 2020). The strips could be horizontally or vertically bonded. This study shows the results of an experiment to determine the effects of bamboo species on the properties of GLBL with vertical orientation made from *Dendrocalamus asper, D. giganteus, D. latiflorus* and *Gigantochloa levis,* glued with water based polymer-isocyanate (WBPI) adhesive.

MATERIALS AND METHODS

Ten mature culms of 4-year old bamboo from four species i.e. betung bamboo (*D. asper*) collected from Garut, West Java, sembilang bamboo (*D. giganteus*) and taiwan bamboo (*D. latiflorus*) collected from Bogor Botanical Garden, and peting bamboo (*G. levis*) collected from Lampung were used in the experiment. Boron solution 7% w/v and water-based polymer-isocyanate (WBPI) Koyobond grade KR-560, crosslinked with grade AP, were used as preservative and adhesive, respectively.

Preparation of bamboo strips

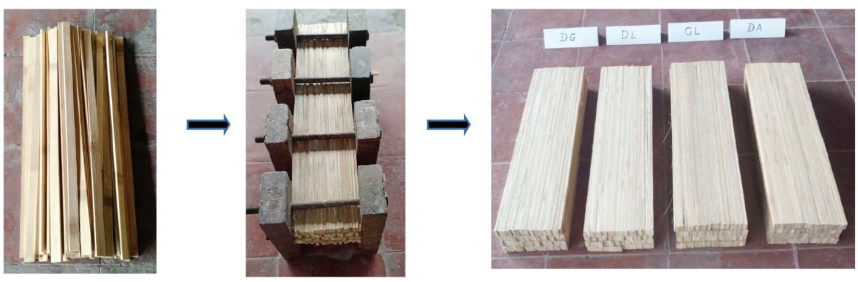
In the experiment, only the middle part of bamboo culms were used. Ten bamboo culms of each bamboo species, measuring about 5 m in length, were cross cut into segments. To produce bamboo strips, each bamboo segment (125 cm in length) was manually fed into a bamboo splitter machine. Depending on the diameter of culm, seven to nine strips were obtained from each segment, each about 2 cm wide. Only straight bamboo strips were used for this study. After scraping out the inner and outer layers, the selected strips with approximately 5.5 mm to 6.5 mm in thickness were stacked for air drying at room temperature for one week. Then, the bamboo strips were immersed in 7% w/v boron solution for four hours, after which they were sun-dried to about 12% moisture content.

Production of laminated bamboo lumber

Laboratory-scale GLBL, vertically glued with dimensions of 60 cm × 16 cm × thickness, were fabricated by assembling 26–28 bamboo strips, vertically arranged side-by-side and wide-glued. The GLBL was manufactured using WBPI adhesive (100 KR-560:15 AP) with a glue spread of 250 g m^{-2} and cold-pressed using a wooden clamp for one hour (Figure 1). Force was applied to the wooden clamps by tightening the screws until 40 ft.lbs or 54.24 Nm as indicated in the micrometer adjustable torque wrench. Four replications were prepared for each GLBL. The GLBL produced was conditioned at room temperature for two weeks before testing.

Testing

The GLBL was cut into desired specimen dimensions and measured for air dry density (ADD), moisture content (MC), water absorption (WA), thickness swelling (TS), width expansion (WE), modulus of rupture (MOR), modulus of elasticity (MOE), bonding strength (BS), bamboo failure (BF), delamination, compression strength (CS) and hardness (HN). The tests for physical and mechanical properties were performed using the American Standard ASTM D 1037-93 (ASTM 1995). The test for BS (block shear and BF) and delamination were performed using Japanese Standard for glued laminated timber (JAS 2007). A completely randomised design (CRD) was used for the bamboo species as a treatment factor.



Bamboo strips | Wooden clamps | GLBL of *Dendrocalamus giganteus, Dendrocalamus latiflorus, Gigantochloa levis* and *Dendrocalamus asper*

Figure 1 Assembling process of vertically GLBL

RESULTS AND DISCUSSION

Physical properties

The mean values of the physical properties of GLBL, the results of analysis of variance (ANOVA), and the results of HSD are presented in Table 1. The MC of GLBL varied from 12.2 to 13.1% with an average of 12.8%. These values were within the range of air-dried MC and conform to the MC requirement for wood-based panel, glued laminated timber products and flooring. The MC of GLBL was affected by the bamboo species.

The ADD of GLBL produced varied from 0.59 to 0.85 g cm^{-3} with an average of 0.69 g cm^{-3}. These values were close to those reported by Paes et al. (2009) which were 0.68 to 0.76 g cm^{-3} for GLBL of *D. giganteus* glued with resorcinol adhesive. The ADD of *D. asper* strips used in this study was 0.76 g cm^{-3}, while the ADD of *D. giganteus, D. latiflorus and G. levis* were 0.59, 0.48 and 0.56 g cm^{-3}, respectively. According to Dransfield & Widjaja (1995) the specific gravity of *D. asper*, *D. giganteus* and *G. levis* were about 0.7, 0.71 and 0.5–0.6 respectively. The average ADD value of GLBL were higher than the original ADD of bamboo strips from raw material. Higher value of ADD in GLBL could be due to the pressure applied and the use of adhesive during laminated bamboo lumber (LBL) manufacturing, which produced a denser product. A previous study found that the use of medium molecular weight phenol formaldehyde (MMwPF) resin increased the density of phenolic treated plywood (Fadhlia et al. 2017). The study applied MMwPF to bamboo (*G. scortechinii*) as opposed to control.

ANOVA showed that ADD of GLBL was affected by the bamboo species. The lowest ADD of GLBL was produced from *D. latiflorus* while the highest ADD of GLBL was produced from *D. asper*.

The WA and TS of GLBL varied from 15.3 to 33.5% and 2.4 to 3.2% with an average of 27.3 and 2.9%, respectively. A previous study on engineered bamboo product such as four-layered GLBL made from moso bamboo (*Phyllostachys pubescens*) zephyr mats glued with resorcinol-based adhesive had average WA and TS of 24.83 and 12.13% (Nugroho & Ando 2001). Laboratory made three-layered GLBL and natural bamboo flooring from moso bamboo strips had WA of 10.04 and 24.62% and TS of 0.96 and 0.69% (Lee & Liu 2003). Three-layered GLBL made from andong bamboo (*G. pseudoarundinacea*) strips, glued horizontally with tannin resorcinol formaldehyde, had TS of 1.03% (Sulastiningsih et al. 2005). Seven layered parallel strand lumber from calcutta bamboo (*D. strictus*) glued with PF exhibited WA and TS of 14.29 and 2.85% (Ahmad & Kamke 2011). TS of bamboo composite lumber made of *G. pseudoarundinacea* glued with WBPI adhesive varied from 1.68 to 2.90% (Sulastiningsih et al. 2018). Another study carried out by Jimenez and Natividad (2019) showed that arc-GLBL made of *Bambusa blumeana,* glued with PVAc and polyurethane (PU), had WA and radial TS varying from 12.89 to 24.19% and 1.76 to 2.9% respectively, while those made from *G. levis* had WA and radial TS varying from 13.93

Table 1 Physical properties of LBL, the results of ANOVA and HSD

Properties	Bamboo species				ANOVA results
	DA	DG	DL	GL	
MC (%)	12.2^{b} (0. 07)	12.9^{a} (0.13)	13.0^{a} (0.12)	13.1^{a} (0.05)	**
ADD (g cm^{-3})	0.85^{a} (0.01)	0.64^{c} (0.01)	0.59^{d} (0.03)	0. 69^{b} (0.02)	**
WA (%)	15.3^{c} (0.5)	28^{b} (0.6)	32.4^{ab} (3.8)	33.5^{a} (1.7)	**
TS (%)	3.0^{a} (0.2)	2.4^{b} (0.2)	3.2^{a} (0.32)	2.9^{ab} (0.3)	**
WE (%)	2.4^{d} (0.07)	3.4^{b} (0.3)	4.0^{a} (0.24)	2.6^{c} (0.17)	**
Delamination (%)	0	0	0	0	-

Each value is the average of four specimens, values in parentheses are standard deviations; DA = *Dendrocalamus asper,* DG = *Dendrocalamus giganteus,* DL = *Dendrocalamus latiflorus,* GL = *Gigantochloa levis*; MC = moisture content, ADD = air-dry density, TS = thickness swelling, WE = width expansion, WA = water absorption; ** = highly significant; values followed with the same letter within the same row are not significantly different to 25.40% and 2.02 to 5.37% respectively. Thus, composite products made from bamboo strips had better dimensional stability than bamboo zephyr mats. A previous study showed that site influenced the dimensional stability of bamboo (Aguinsatan et al. 2019). The swelling test of *D. asper* showed that upland bamboo reabsorbed less water than the riparian bamboo, thus the former was more superior than the latter (Aguinsatan et al. 2019). The data on WA and TS were subjected to ANOVA, and the result showed that WA and TS of GLBL was significantly affected by bamboo species. The GLBL made from *D. giganteus* had the best dimensional stability.

The WE of GLBL varied from 2.4 to 4.0% with an average of 3.1%. This finding is similar to previous studies which reported that the WE of laminated bamboo beam made from andong bamboo strips, glued vertically with WBPI adhesive, was 2.4%, while the WE of GLBL made of andong bamboo strips, glued horizontally with urea-formaldehyde (UF) adhesive, varied from 2.0 to 2.7% (Sulastiningsih & Santoso 2012, Sulastiningsih et al. 2016a). Another study by Lee and Liu (2003) reported that the WE of laboratory made three-layered GLBL and natural bamboo flooring made from moso bamboo strips were 0.74 and 0.12%, respectively. Thus, natural bamboo flooring had the lowest WE, possibly due to the presence of lacquer on the surface, prior to the specimen being tested, which may have prevented water from entering the bamboo.

The data on WE were subjected to ANOVA using CRD and the results showed that WE of GLBL was affected by the bamboo species. The WE of GLBL decreased with increasing ADD of GLBL. Higher ADD GLBL has smaller voids, thus, WA into the lumber occurred at a slower rate and resulted in lesser amount of absorbed water. The slow rate of WA was also observed in sembilang bamboo (*D. giganteus*) strips treated with 1% copper chrome borate (CCB). Boron salt in CCB increased GLBL stability, as it filled the cellulose-hemicelluloses-lignin matrix and impeded the movement of water molecules (Paes et al. 2009).

The bonding quality of any composite product is very important. In this study, delamination test was used to determine the bonding quality of multilayered composite product. Data from the boiling water delamination test showed that there was no delamination in all samples, and therefore, the bonding quality of GLBL made from the four bamboo species were considered acceptable, and meet the standard requirement for laminated veneer lumber, glued laminated timber and composite flooring (JAS 2007, 2008, 2013). The Japanese Agricultural Standard (2013) stated that the length of the delaminated part of the same bonding layer of the test piece shall be not more than one third of its side length.

Mechanical properties

The mean values of mechanical properties of GLBL, the results of ANOVA, and the results of HSD are presented in Table 2. The MOR and MOE of vertically GLBL varied from 727 to 1466 kg cm^{-2} and 91,379 to 161,597 kg cm^{-2}, respectively. The highest MOR and MOE values resulted from GLBL made from *D. asper*, while the lowest MOR and MOE values resulted from *D. latiflorus*. The MOR for GLBL from *D. giganteus* was higher than that reported by Paes et al. (2009), who found that CCB treated GLBL glued with PVAc had the highest MOR value, 914.38 kg cm^{-2}. The MOR and MOE of GLBL (vertical laminates) made from *B. bambos*, glued with PF, was 145.2 N mm^{-2} or 1480 kg cm^{-2}, and 16,800 N mm^{-2} or 171,282 kg cm^{-2}, respectively (Bansal & Prasad 2004). These values were higher than the MOR of GLBL made of the four bamboo species in this study. The MOR of vertically GLBL beam made of *G. pseudoarundinacea*, glued with isocyanate adhesive, was 958.3 kg cm^{-2}, while the MOR and MOE of bamboo composite lumber in combination with wood as the core layer, varied from 613 to 1162 kg cm^{-2} and 74,758 to 173,757 kg cm^{-2} (Sulastiningsih et al. 2016a, 2018).

Another previous study reported that MOR and MOE of a three-layered GLBL (horizontal laminates) made from bamboo strips of *G. pseudoarundinacea*, glued with tannin recorcinol formaldehyde (TRF), were 1241 and 133,615 kg cm^{-2}, and those GLBL made from *G. apus* had MOR and MOE values of 969.4 kg cm^{-2} and 102,290 kg cm^{-2} respectively, whereas the GLBL made from *G. robusta*, glued with isocyanate adhesive, had MOR value of 1124 kg cm^{-2} (Sulastiningsih et al. 2005, Sulastiningsih & Nurwati 2009, Sulastiningsih et al. 2016b). Another study carried out by

Jimenez & Natividad (2019) reported that arc-LBL made from *G. levis*, glued with PVAc and PU, had MOR and MOE values varying from 56 MPa (571 kg cm^{-2}) to 72 MPa (734.2 kg cm^{-2}) and 7 GPa (71,380 kg cm^{-2}) to 9 GPa (91,775 kg cm^{-2}), respectively. The MOR and MOE of glue-laminated colombian bamboo (*Guadua angustifolia*), produced with PVAc, were 81.9 MPa or 835 kg cm^{-2} and 19,140 MPa or 195,174 kg cm^{-2}, respectively (Correal & Lopez 2008). The MOR and MOE of LBL (vertical laminates) made of *B. bambos*, glued with MUF, were 149.1 N mm^{-2} or 1520.4 kg cm^{-2}, and 16,570 N mm^{-2} or 168,967 kg cm^{-2} (Bansal & Prasad 2004). The study also revealed that the MOR and MOE of GLBL (horizontal laminates) were 164.4 N mm^{-2} or 1676.4 kg cm^{-2}, and 17,300 N mm^{-2} or 176,411 kg cm^{-2}, respectively (Bansal & Prasad 2004).

The data on MOR and MOE of GLBL was subjected to ANOVA, and the results showed that the MOR and MOE of GLBL was affected by bamboo species. It also showed that the correlation between ADD and MOR, and MOE were significant ($p < 0.01$) with correlation coefficients of 8.79 and 9.10, respectively. The regression equations were:

MOR: $Y = -833.9 + 2622X$

MOE: $Y = -41\ 523 + 242\ 911X$

The increase in ADD of GLBL increased MOR and MOE of GLBL. In addition, a study investigating the influence of site on the mechanical properties of *D. asper* found that bamboos growing in upland areas have higher MOR and MOE values compared to those grown in riparian areas (Aguinsatan et al. 2019).

Compared to Indonesian wood strength class (Oey 1999), based on MOR value, the GLBL from *D. asper* bamboo strips had comparable strength to wood strength class I (> 1100 kg cm^{-2}), and those GLBL from *D. giganteus* and *G. levis*, to wood strength class II, while the GLBL from *D. latiflorus*, to wood strength class III. The possible reason which contributed to the higher strength of GLBL made of *D. asper* is the higher lignin content (32.35%) compared to others bamboo species (24–24.76%) (Damayanti et al. 2019).

The CS of GLBL varied from 463 to 720 kg cm^{-2} with an average of 550 kg cm^{-2}. A previous study (Bansal & Prasad 2004) reported that GLBL (vertical laminates) made from *B. bambos*, glued with MUF, had an average CS value of 84.7 N mm^{-2} (or 864 kg cm^{-2}) which was higher than the CS of GLBL made from the four bamboo species in this study. The CS of vertically glued laminated bamboo beam from *G. pseudoarundinacea*, glued with isocyanate adhesive, was 646.8 kg cm^{-2} (Sulastiningsih et al. 2016a), while those bamboo composite lumber from *G. pseudoarundinacea*, in combination with wood as core layer, had CS values varying from 364.6 to 644.7 kg cm^{-2} (Sulastiningsih et al. 2018). Another previous study carried out by Correal and Lopez (2008) reported that

Table 2 Mechanical properties of LBL, the results of ANOVA and HSD

Property	Bamboo species				ANOVA results
	DA	DG	DL	GL	
MOR (kg cm^{-2})	1466 (38)^a	974 (42)^b	727 (16)^c	757 (30)^c	**
MOE (kg cm^{-2})	161,597^a (5 768)	114,903^c (2 069)	91,379^d (2 423)	138,393^b (9 204)	**
CS (kg cm^{-2})	720 (84)^a	540 (48)^b	463 (97)^b	477 (46)^b	**
HN (kg)	556 (78)^a	474 (33)^a	286 (41)^b	293 (65)^b	**
BS (kg cm^{-2})	64 (12)^a	65 (5)^a	58 (3)^a	60 (10)^a	ns
BF (%)	90 (13)^a	80 (16)^a	60 (10)^b	80 (18)^a	*

Each value is the average of four specimens except for bonding strength which had twelve specimens, values in parentheses are standard deviations; DA = *Dendrocalamus asper*, DG = *Dendrocalamus giganteus*, DL = *Dendrocalamus latiflorus*, GL = *Gigantochloa levis*, MOR = modulus of rupture, MOE = modulus of elasticity, CS = compression strength, HN = hardness, BS = bonding strength, BF = bamboo failure; * = significant, ** = highly significant, ns = not significant; values followed with the same letter within the same row are not significantly different the CS of glue-laminated colombian bamboo (*G. angustifolia*), manufactured using PVAc adhesive, was 47.6 MPa (or 485 kg cm^{-2}). The CS of three-layered GLBL (horizontal laminates) from *G. apus*, glued with TRF, was 564.8 kg cm^{-2}, while CS of GLBL from *G. pseudoarundinacea*, glued with UF, varied from 522 to 580 kg cm^{-2} with an average of 562 kg cm^{-2} (Sulastiningsih & Nurwati 2009, Sulastiningsih & Santoso 2012).

The data on CS of vertically GLBL was subjected to ANOVA and the results showed that CS of GLBL was affected by bamboo species. The highest CS value resulted from GLBL from *D. asper*, while the lowest CS value was from GLBL made of *D. latiflorus*. Compared to Indonesian wood strength class (Oey 1999), based on CS value, the GLBL made of *D. asper* had strength values comparable to wood strength class I (> 650 kg cm^{-2}), while GLBL made of *D. giganteus, D. latiflorus and G. levis* had strength values comparable to wood strength class II (425–650 kg cm^{-2}).

The HN of vertically GLBL varied from 286 to 556 kg with an average of 402 kg. The HN is an important property for flooring material. It measures the capability to endure indentation, scratches and loads. The HN value is corresponding with specific gravity, drying temperature and the impregnation process of the material (Mohd-Jamil 2016). The HN of engineered bamboo (e-bamboo) from various companies in Philippines varied from 2.6 kN (or 265.13 kg) to 7.1 kN (or 724 kg) (Alipon & Cabangon 2013). The average ADD of *D. asper* strips used in this study was 0.76 g cm^{-3}, while the average ADD of *D. giganteus, D. latiflorus and G. levis* were 0.59 g cm^{-3}, 0.48 g cm^{-3} and 0.56 g cm^{-3}, respectively. The data on HN were subjected to ANOVA using CRD and the results (Table 2) showed that the HN of vertically GLBL was affected by bamboo species. The GLBL from *D. asper* exhibited the highest HN value, while the GLBL from *D. latiflorus* exhibited the lowest value.

The HN of five-layered GLBL with various layer orientation, made of *G. pseudoarundinacea*, glued with WBPI adhesive, varied from 532 to 626.5 kg with an average of 585.8 kg (Sulastiningsih 2014). In this study, the HN of *D. asper* GLBL (vertical laminates) (556 kg) was higher than that of engineered bamboo boards (5.06 kN or 516 kg) made of *D. asper* glued with various types of adhesive (Alipon et al. 2018). Another study reported that the HN of bamboo composite lumber, manufactured with various layer compositions of *G. pseudoarundinacea*, in combination with wood planks of jabon (*Anthocephalus cadamba*), manii (*Maesopsis eminii*) or sengon (*Falcataria moluccana*), glued with WBPI adhesive, varied from 352.3 to 552.7 kg with an average of 405 kg (Sulastiningsih et al. 2018).

Hardness is a practical mechanical property used to assess the suitability of a wood species for use as residential and/or commercial flooring (Wiemann & Green 2007). The wood species commonly used for fancy flooring is jati (*Tectona grandis*). The HN of jati was 428 kg (Martawijaya et al. 2005). Thus, the HN of vertically GLBL made from *D. asper* (556 kg) and *D. giganteus* (474 kg) were higher than that of jati. Therefore, the GLBL is suitable for flooring. However, the HN requirement has not been stated in the flooring standard (JAS 2013, ISO 2014). Further, the HN parameter in the required ISO is only applicable for paint film performance (ISO 2014).

The BS of vertically GLBL varied from 58 to 65 kg cm^{-2} (Table 2). The data on BS were subjected to ANOVA using CRD and the results (Table 2) revealed that the bamboo species did not affect the BS of vertically GLBL. The average BS of LBL made from *B. bambos* (vertical laminates), glued with PF, was 12.7 N mm^{-2} (or 129 kg cm^{-2}) while that of GLBL (horizontal laminates), glued with MUF, was 9.65 N mm^{-2} or (98 kg cm^{-2}) (Bansal and Prasad 2004). Another study carried out by Correal and Lopez (2008) reported that colombian glued laminated bamboo produced with PVAc adhesive had BS value of 7.92 MPa (or 80.8 kg cm^{-2}). The average BS of a three-layer laminated bamboo board (horizontal laminates) made from *G. robusta*, glued with TRF, was 55.8 kg cm^{-2} (Sulastiningsih and Nurwati 2009), while those of isocyanate-bonded laminated bamboo lumber made of *G. robusta* varied from 55.4 to 62.2 kg cm^{-2} (Sulastiningsih et al. 2016b). The laminated guadua bamboo (*G. angustifolia*), glued with UF and MF, had average BS of 12.55 MPa (or 128 kg cm^{-2}) and 12.73 MPa (or 129.7 kg cm^{-2}), respectively (Correal & Ramirez 2010). Thus, the BS of various LBL was not affected by bamboo species, but type of adhesive.

In this study, the BQ was assessed by BS and BF. The BF ratio, as percent of total fracture area, can be used as an indicator of BQ. The greater the BF ratio, the better the BQ of the product. The BF ratio of vertically GLBL made of the four bamboo species varied from 60 to 90% (Table 2). The BF ratio of GLBL (vertical laminates) was lower than that of glued laminated guadua bamboo, i.e. 94% (UF) and 96% (MF) (Correal & Ramirez 2010). The data on BF ratio were subjected to ANOVA using CRD. The results (Table 2) showed that bamboo species affected the BF ratio of vertically GLBL. The highest BF ratio resulted from vertically GLBL from *D. asper*, while the lowest BF ratio resulted from vertically GLBL from *D. latiflorus*.

CONCLUSIONS

The physical and mechanical properties of vertically GLBL was affected by bamboo species. Based on the Indonesian wood strength classification, vertically GLBL from *D. asper* had strength values comparable to wood strength class I, while those from *D. giganteus*, *D. latiflorus* and *G. levis*, to class II. All vertically GLBL produced were suitable for solid wood substitute or complement as furniture and building component materials. Vertically GLBL from *D. asper* and *D. giganteus* was also suitable for flooring material.

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