Evaluation of Screw Pulling and Flexural Strength of Bamboo-based Oil Palm Trunk Veneer Hybrid Biocomposites Intended for Furniture Applications

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Screw withdrawal and flexural strength were evaluated for *Dendrocalamus asper* and *Gigantochloa levis* bamboo species to explore the possibility of their use as structural material in place of wood. Dry bamboo strips and 4-mm-thick oil palm trunk veneer (OPTV) were processed into thin laminates and hot-pressed using urea formaldehyde resin to produce bamboo-OPTV hybrid biocomposites. Bamboo furniture is far more resistant to damage than traditional hardwoods. Bamboo is even used in cutting boards for this reason. Even though there have been some reports on the mechanical enhancement of the bamboo-based composites, so far there has been no comprehensive study on the screw pulling and flexural strength of bamboo-based hybrid composites. The results revealed a stronger correlation of the bamboo hybrid under screw withdrawal and flexural strength, but there was a weaker correlation in the mechanical properties of the bamboo hybrid due to the random selection of laminate from different bamboo species. Furthermore, test results clearly showed that bamboo-OPTV hybrid biocomposites can be used as an alternative to wood and wood-based composites for furniture applications.

Keywords: Bamboo; Biocomposites; Furniture; Hybrid; Mechanical properties; Screw withdrawal; Flexural

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INTRODUCTION

Indigenous plants, such as bamboo and oil palm, thrive in tropical and subtropical regions worldwide. Bamboo is an industrial crop that belongs to the family Gramineae and the subfamily Bambusiodeae, and grows naturally in many countries including Malaysia. Bamboo, as a fast-growing renewable material with a simple production process, is now being explored as a sustainable alternative for more traditional structural materials, such as concrete, steel, and timber. Due to its favorable mechanical properties, high flexibility, fast-growing rate, low weight, and low purchasing costs, bamboo is a building material with many opportunities (Rao and Rao 2007). It can be used in many applications from traditional handicraft to products that are completely industrialized including construction, interior design and decorations, furniture, automotive components, and more (Van der Lugt *et al.* 2006; Abdul Khalil *et al.* 2015; Hakeem *et al.* 2015).

For decades, Malaysia has held the title as one of the most productive palm oil producers in the world (Yusoff 2006; Sayer *et al.* 2012). Without a doubt it has become the most important agricultural crop in Malaysia and has been the key to national economic expansion (Hashim *et al.* 2010; Shafie *et al.* 2011). The main problem in oil palm tree cultivation and its related industries is its substantial amount of biomass wastes generated after harvesting the oil palm fruits, the palm oil processing, or during the replanting of oil palm trees (Abdullah and Sulaiman 2013). Approximately 75% of the wastes in the form of oil palm trunks (OPT) and oil palm fronds (OPF) are left rotten in the plantation for mulching and nutrient recycling purposes. Extensive research has provided an alternative way of optimizing the usage of oil palm residues into value-added products. For example, there is a serious interest in using OPT as a substitute for some wood products for structural applications, including composite material and reinforcing agents (Abdul Khalil *et al*. 2012; Cheng *et al*. 2016).

Today, various initiatives have started to produce natural fibre from alternative materials like lignocellulosic biomass because of its low cost, sustainability, and availability (Nurul Fazita *et al.* 2016). Malaysia is aggressively trading lignocellulosic fibres to produce a suitable material for furniture applications. Recently, efforts have been made on research related to lignocellulosic biomass waste material for some potential applications. Lignocellulose from agricultural waste, such as oil palm trunk veneer (OPTV), has become important in the composite industry. To meet increasing demands for laminated composite-based products, developing non-tree wood alternatives is one of the means to solve the wood shortage without cutting down trees (Koronis *et al.* 2013). Laminated composites are formed when the fibres are reinforced with a matrix that consists of several layers of fibre (Ajitanshu 2019; Rizal *et. al* 2018).

Advances in science and technology enable the world's manufacturing industry to control and improve the overall properties of alternative materials to replace the conventional materials. Technology-based research with the focus on bamboo species, such as *Dendrocalamus asper* and *Gigantochloa levis*, through high potential hybrids with OPTV can be applied in many applications, such as furniture components (Othman *et al.* 2012). Methods for the preparation of laminated bamboo hybrid with palm veneer biocomposites (LBHC) have been suggested and mechanical properties, mode of failure, and analysis of bamboo species for LBHC have been discussed in this paper to determine their usability. A stress-strain model was developed on the basis of performance of LBHC under a flexural strength test and screw withdrawal test to prove that the LBHC can be considered as a suitable material for furniture. Properties and quality of innovative composites, especially laminated composite products, can be further improved through research (Suhaily *et al.* 2012). Therefore, mechanical properties of bamboo laminate with OPTV have been investigated and compared with a similar type of bamboo species so that the full potential of bamboo as a functionally laminated composite can be realized.

EXPERIMENTAL

Materials

Fabrication of LBHC

The green bamboo species, *D. asper* and *G. levis*, of 4 years were obtained from the Forest Research Institute Malaysia (FRIM), Kepong Selangor, Malaysia. Full lengths of bamboo culms were labeled at the nodes and internodes as shown in Fig. 1. The bamboo culms were cut at approximately 25 cm above the ground. A bamboo culm thickness of ≥ 20 mm was selected for each species in this research. The thickness of the bamboo is necessary for producing high quality bamboo strips with uniform thickness.

All of the bamboo samples were transported to the bamboo factory at Negeri Sembilan, Malaysia to process the bamboo culms into bamboo strips. At the early stage, all bamboo culms were immersed in water for three weeks and then treated with an antifungal chemical, such as borax and deltamethrin, to prevent fungus and insect attacks, while at the same time making the bamboo more durable. A machete was used to create a vertical incision on each bamboo culm to manually split the bamboo culm into a width of 2.5 cm and a length of 1 m. Next, a clamping machine was used to remove the outer skin of the bamboo strips and a flattener machine was used to flatten and trim the surface.

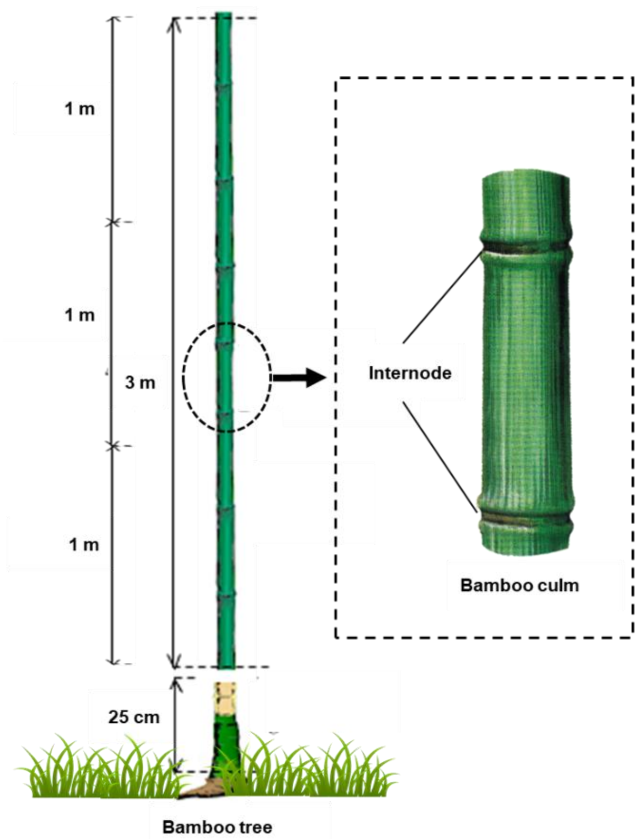

Fig. 1. Cutting measurement of bamboo tree

The OPTV were produced from OPT waste materials 25- to 30-years-old that were cut after reaching maturity. The skin of OPT was peeled off, the OPT was processed to become veneer, and then it was cut to 4-mm thickness. The OPTV were air-dried to a moisture content (MC) between 10% and 12%. The MC of bamboo strips and air-dried MC was measured between 10% and 12%.

In the parallel arrangements, bamboo pieces were placed parallel to the OPTV pieces, while in the perpendicular arrangements the bamboo pieces were at 90° to the grain (Fig. 2). The samples were then arranged into a 5-ply biocomposite alternately consisting of pieces of bamboo strips and pieces of OPTV. The layers were then glued using urea formaldehyde (UF) resin, which is a general-purpose liquid resin and was supplied by Al

Asia Chemical Industry Sdn. Bhd. located in Pulau Pinang, Malaysia. The adhesives were uniformly spread on the pieces of bamboo strips and pieces of OPTV using a brush prior to fixing. Although the veneer's surface was rough, even application and control of the spread of the resin was easy. Both surfaces had to be applied rather than just on the surface to achieve the maximum bond between the bamboo strips and OPTV (Kollman *et al.* 1975). The adhesive spread level was 203.6 g/m^2, and it was important to determine the quality of the composites. The equation to measure the spread level (SL) is given as Eq. 1,

$$SL = \frac{g}{m^2} \tag{1}$$

where g is the weight of the adhesive (g) and m^2 is the surface area of the veneer (mm).

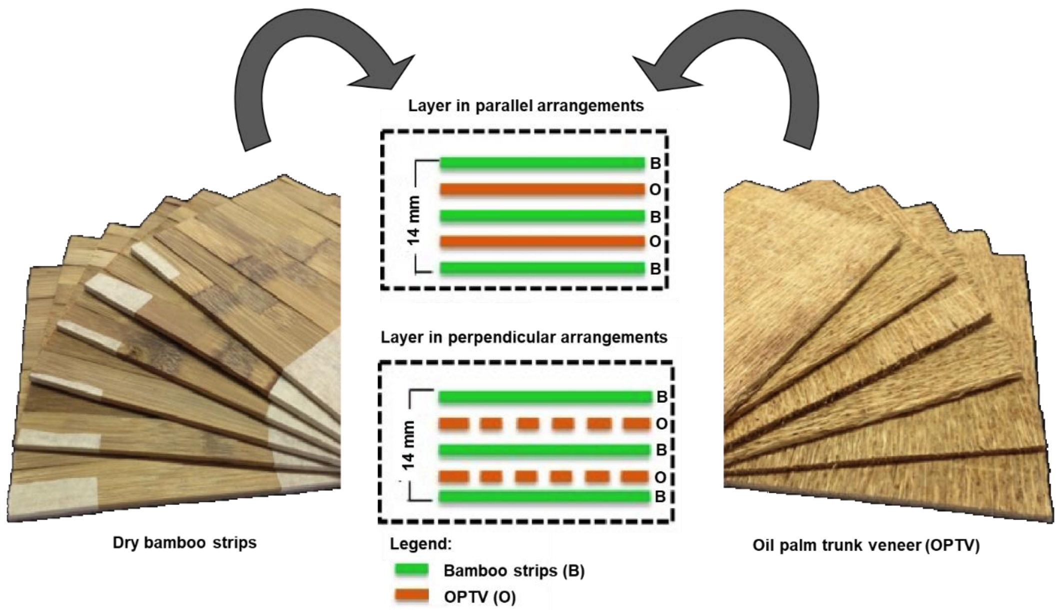

Fig. 2. Layer of bamboo strips and OPTV in parallel and perpendicular arrangements

The layers of bamboo strips and OPTV were then assembled, stacked together, and later were cold-pressed. During the cold-press process, the pressure was applied using the compression hydraulic press machine (Model: GT-7014; Gotech Testing Machines Inc., Taichung City, Taiwan) at room temperature for 10 min to form a bond between the surfaces of the raw materials. After 10 min, the stacks were hot-pressed using the same hot press machine at a temperature of 120 °C for a duration of 20 min with 20.68 MPa pressure. Size of each LBHC was set to be 300 mm (length) x 300 mm (width) x 14 mm (thickness). Meanwhile, the density of each composite was 0.93 g/cm and 0.98 g/cm for LBHC from *G. levis* and *D. asper*, respectively. A total of 5 test specimens were prepared from all types of the LBHC samples and each sample was cross-cut as per American Standard Testing Materials (ASTM) standards and European Standards (EN) for flexural and screw withdrawal testing, respectively.

Methods

Flexural test

The flexural strength is the ability of a material to withstand flexural forces applied perpendicular to its longitudinal axis. During application of such forces, numerous mechanisms take place simultaneously, such as tension, compression, and shearing. The modulus of elasticity of the flexural strength was measured *via* applying a load to the center of a test piece supported by two points. The flexural test was performed accordingly to the ASTM D790 (2017) standard using an Instron universal testing machine (Model: UTM 5582; Instron, Norwood, MA, USA). The test specimens were rectangular strips with dimensions of 160 mm (length) × 20 mm (width) × 14 mm (thickness). Collected data were analysed by a one-way analysis of variance (ANOVA) using SPSS Statistics Software (IBM Corporation, Version 14.0, Armonk, NY, USA).

Screw withdrawal test

The screw withdrawal test is a measure of the force required to withdraw a wood screw from the test specimen. The screw withdrawal test was performed using a universal testing machine (Model: AG-15 MS 50KND, Shimadzu, Kyoto, Japan). Steel countersunk wood screws approximately 4.2 mm diameter × 38 mm long were used. The screw withdrawal test was conducted using rectangular strips with the dimensions of 75 mm (length) × 75 mm (width) × 14 mm (thickness). The screw was driven up to 14 mm depth, where the pre-drilled hole was fixed at 7 mm, and the screw was inserted into the hole to the full thickness of the composites. The test was conducted in accordance with EN 320 (1993) and EN 320 (2011) standards.

Fracture surface morphology

Fracture surface morphology was analyzed via scanning electron microscopy (SEM) (EVO MA10; Carl Zeiss SMT, Germany). The acceleration voltage was set at 15 kV, and samples were coated with a very thin layer of gold prior to analysis.

RESULTS AND DISCUSSION

Flexural Strength

The flexural strengths (MPa) of LBHC from *D. asper* and *G. levis* are shown in Fig. 3. From the results, the parallel layer arrangements showed greater strength compared to the perpendicular arrangement. This effect may have been due to the higher density of the laminated composite specimens obtained from the hybrid composites with the UF adhesive. The species *D. asper* gave the highest mean strength on both layer arrangements; in parallel it gave a mean strength of 95.5 MPa, and in perpendicular it gave a mean strength of 83.5 MPa. Both samples exhibited a remarkable difference from each other ($p < 0.05$). There were also remarkable differences ($p < 0.05$) between the layer arrangements (parallel or perpendicular) with its control (parallel or perpendicular), with mean differences of 40% (parallel *vs.* parallel-neat composite) and 36% (perpendicular *vs.* perpendicular-control).

The LBHC using *G. levis* arranged with the parallel arrangement gave the mean strength of 88.4 MPa, and the perpendicular arrangement gave 81.4 MPa. Both exhibited noticeable differences to each other ($p < 0.05$) and they were also apparently lower in strength when compared to *G. levis* in both the parallel and perpendicular arrangements ($p < 0.05$). There were remarkable differences ($p < 0.05$) between the layer arrangements (parallel or perpendicular) with their neat composite (parallel-neat composite or perpendicular-neat composite), with mean differences of 40% (parallel *vs.* parallel-neat composite) and 37% (perpendicular *vs.* perpendicular-neat composite).

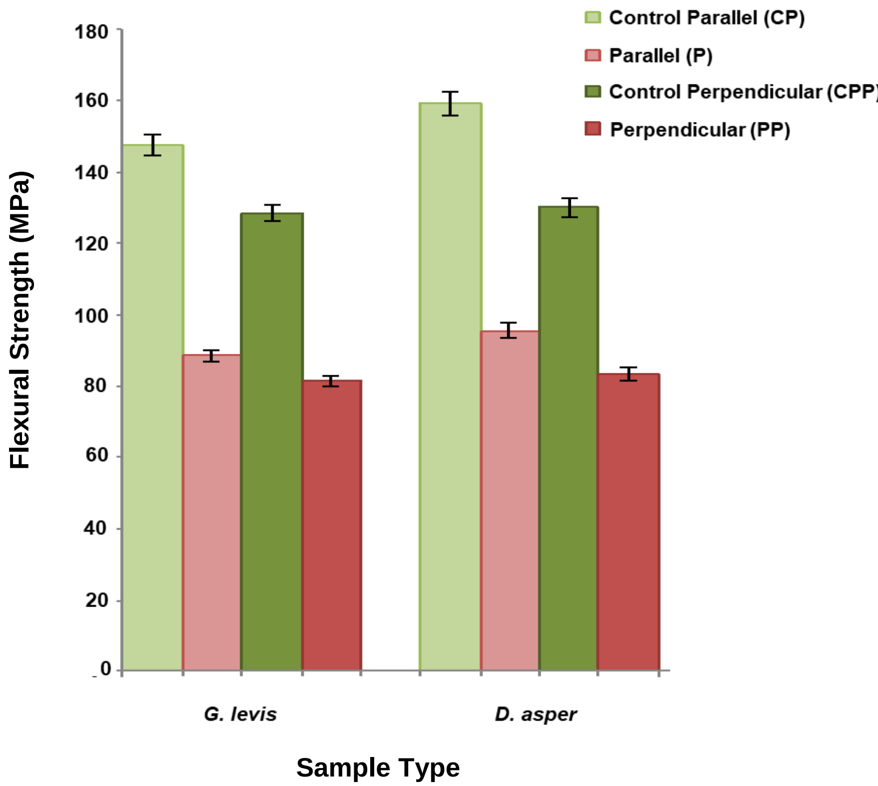

Fig. 3. Flexural strength of LBHC from *G. levis* and *D. asper* at different layer arrangements

Flexural Modulus

The flexural moduli (GPa) of LBHC from *G. levis* and *D. asper* are shown in Fig. 4. From the results, the arrangements of the parallel layer of the neat composite showed greater strength compared to the perpendicular layer of the neat composite arrangement. This effect may have been due to the higher density of the laminated composite specimens obtained from the hybrid composites with the UF adhesive. The species *G. levis* gave the mean modulus of 5.52 GPa on the arrangement with parallel layers that was lower than *D. asper*. Similarly, *G. levis* had a lower flexural modulus at the perpendicular arrangements when compared to *D. asper*. Furthermore, there were remarkable differences ($p < 0.05$) between the layer arrangements (parallel or perpendicular) with their control composite (parallel-neat composite or perpendicular-neat composite), with mean differences of 30% (parallel *vs.* parallel-neat composite) and 46% (perpendicular *vs.* perpendicular-neat composite).

Furthermore, *D. asper* arranged with the parallel arrangement gave the highest mean modulus of 5.53 GPa, and the perpendicular arrangements gave 4.49 GPa. Both exhibited a significant difference ($p < 0.05$) relative to *G. levis* in their respective layered arrangements. There were significant differences ($p < 0.05$) between the layer arrangements (parallel or perpendicular) with their control composites (parallel-neat composite or perpendicular-neat composite), with mean differences of 29% (parallel *vs.*

parallel-neat composite) and 30% (perpendicular *vs.* perpendicular-neat composite). Higher values of flexural modulus were found for the composites made using the UF adhesive. The higher flexural was due to the UF resin, which, when properly cured, often became tougher and gave a higher flexural modulus. Therefore, UF resin is favoured by many commercial industries for adhesive application, particularly in the manufacturing of forest products (Dunky 1998; Yorur *et al.* 2014).

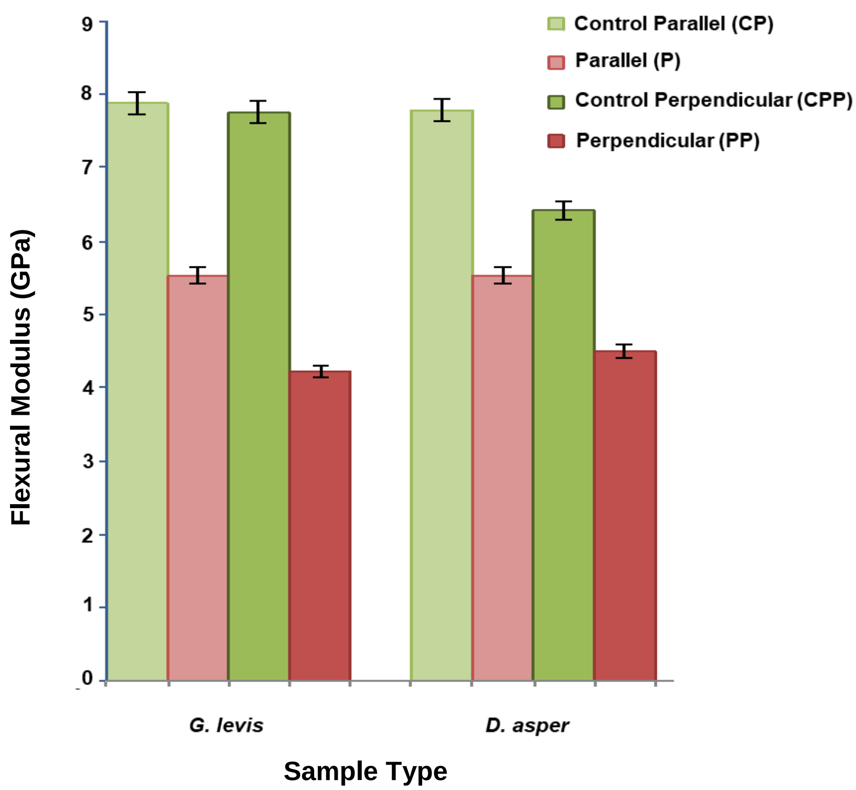

Fig. 4. Flexural modulus of LBHC from *G. levis* and *D. asper* at different layer arrangements

LBHC from *D. asper* species exhibited higher flexural strength, as the bamboo species have higher density as compared to *G. levis*. The results also showed that *D. asper* exhibited superior physical properties. The fibre thickness of the *D. asper* bamboo strips influenced the flexural strength and flexural modulus. The results of the testing identified the failure modes of the laminated layer arrangements, as illustrated in Fig. 5 for the parallel arrangement and Fig. 6 for the perpendicular layers. The results also indicated that the laminated hybrid of OPTV also affected the flexural strength of the LBHC. It was due to the OPTV, which demonstrated lower cellulose content compared to the bamboo, which was high in cellulose. Furthermore, the strength of the fibres was briefly correlated to the cellulose content and microfibrillar angle. Fibres with higher cellulose content, a higher degree of polymerization of cellulose, and a lower microfibrillar angle give better mechanical properties (Reddy and Yang 2005). Therefore, the strength and elasticity of LHBC depended not just on the strength of the species and the dimensions of both bamboo strips and veneer, but also on the number of layers, their relative thickness, and quality of veneer.

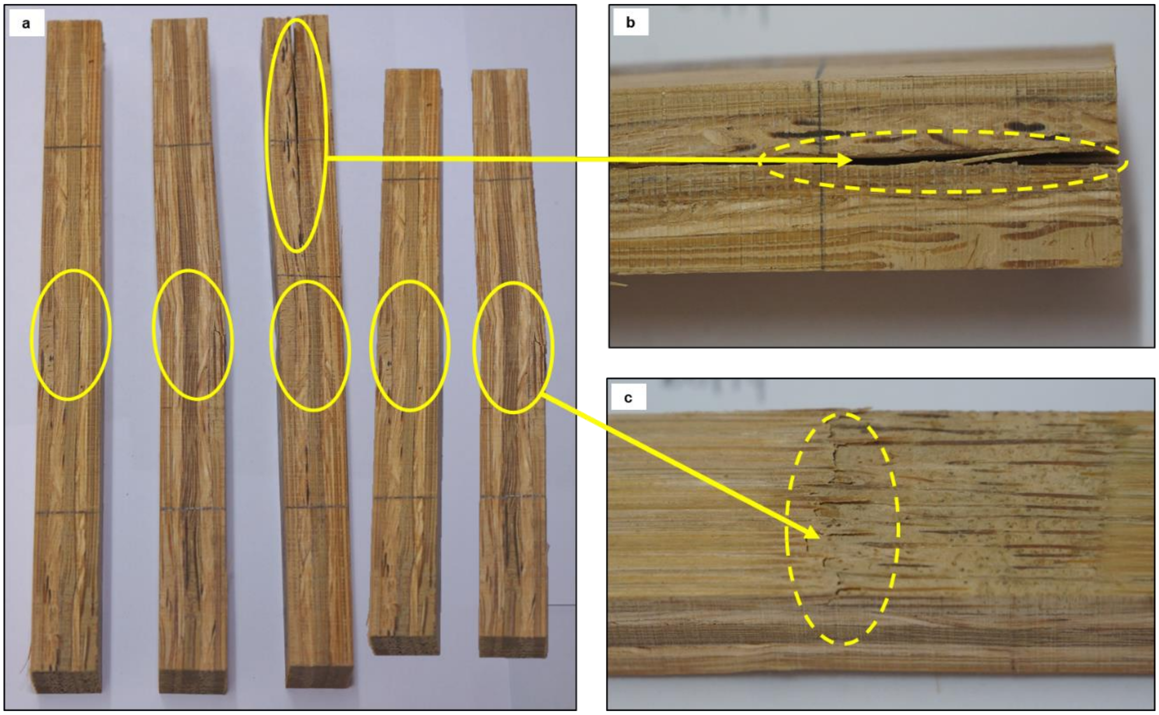

Fig. 5. LBHC samples in parallel arrangement after flexural loading test: (a) samples prepared for testing, (b) fractures at middle end part of side face, and (c) fractures on top middle of samples

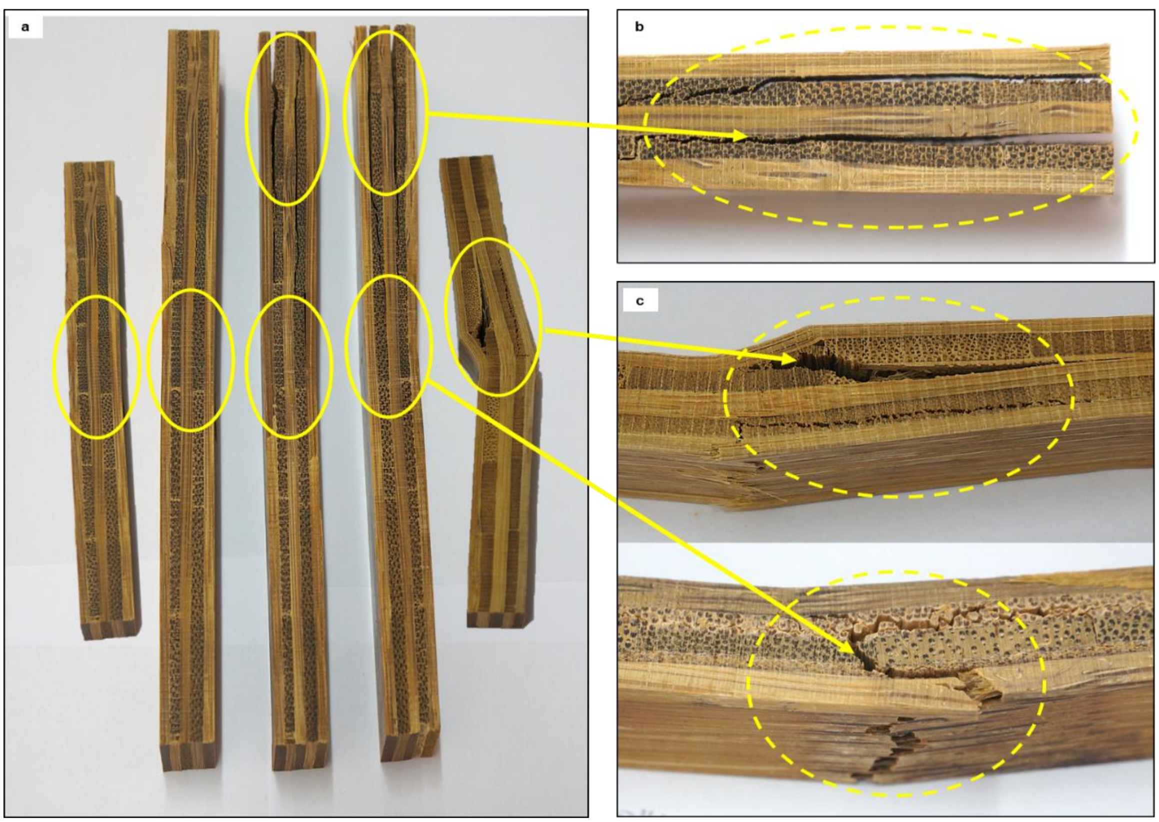

Fig. 6. LBHC samples in perpendicular arrangement after flexural loading test: (a) samples prepared for testing, (b) fractures at end part of side face, and (c) fractures in the middle of the side face

Screw Withdrawal Strength

The withdrawal load varies directly with the depth of penetration of the threaded portion and the diameter of the screw, provided that the screw does not break in the tension. The screw will break in tension when its strength is exceeded by the withdrawal strength of the wood. Figures 7 and 8 show the screw withdrawal test on the load on face of LBHC for *G. levis* and *D. asper* with different layer arrangements using UF resin.

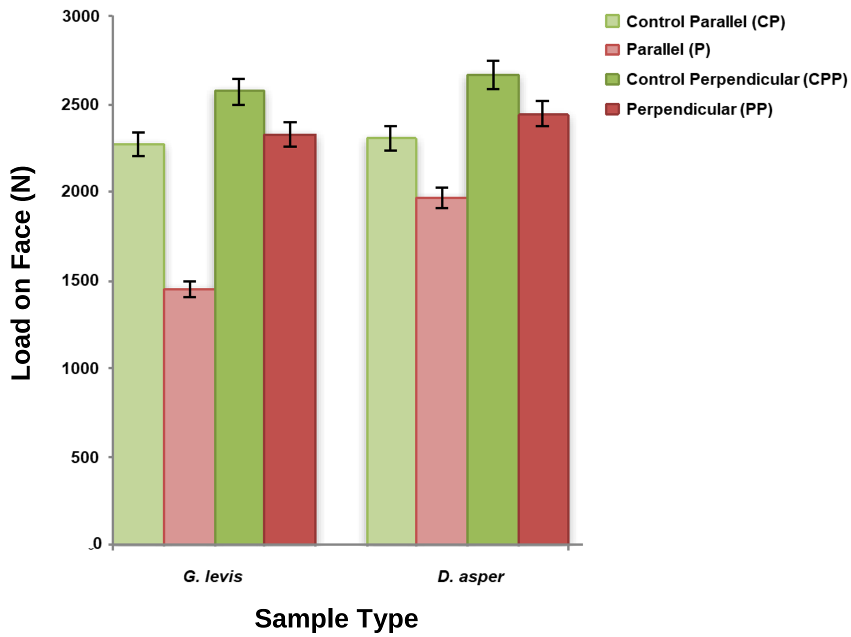

Fig. 7. Screw withdrawals (face) of LBHC shown in different layer arrangements

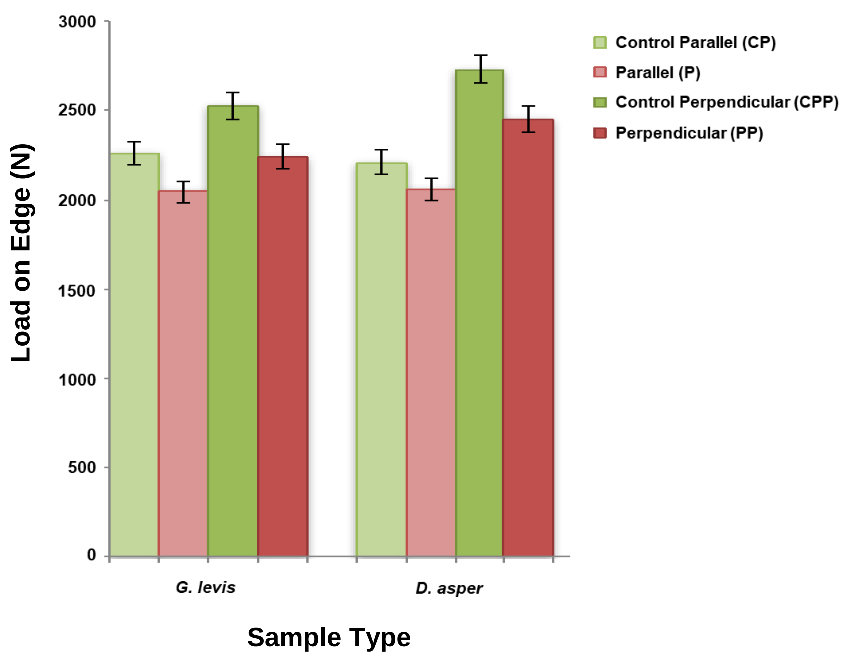

Fig. 8. Screw withdrawals (edge) of LBHC shown in different layer arrangements

For the parallel arrangement, *D. asper* had the highest mean load strength value of 1967 N, followed by *G. levis* that gave 1451 N of screw withdrawal strength. For the perpendicular arrangements, the highest mean resistance values for face screw withdrawal were seen from *D. asper* with a value of 2447 N and *G. levis* with a mean value of 2328 N. The results of the LBHC species *D. asper* for both layer arrangements demonstrated substantially higher values than *G. levis*. The differences may have been influenced by the quantity of glue spread on the composites, which ultimately affected the screw withdrawal properties. The types of bamboo, thickness of layers, and layer orientations also influenced the withdrawal strength of the bolt (Okino *et al.* 2004; Celebi and Kilic 2007; Huseyin *et al.* 2017).

The results also indicated that there was a good correlation between the screw withdrawal strength and the density. The limiting length caused the tension failure to lessen as the density of the LBHC increased because the pull-out strength of the composites increased with density (Huseyin *et al.* 2017). A linear relationship has been reported between the withdrawal strength of the screw with the specific gravity, and the increment of withdrawal strength of the screw was determined from the increased specific gravity values (Celebi and Kilic 2007). The LBHC with the perpendicular arrangement gave a higher resistance value of edge screw withdrawals compared to the LBHC with the parallel arrangement. The perpendicular LBHC species *D. asper* gave the highest mean value of 2057 N and *G. levis* gave a value of 2045 N.

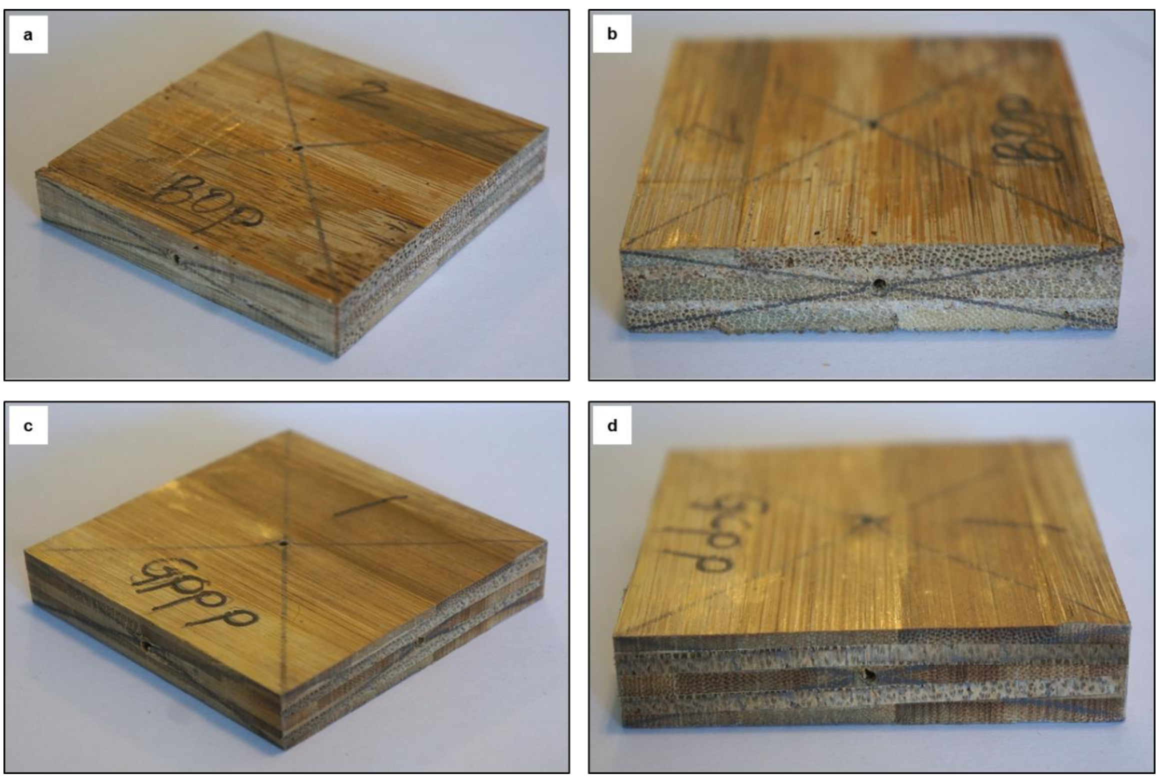

Fig. 9. Surface of samples after screw withdrawal test: (a) top face of LBHC from *D. asper* in parallel arrangements, (b) side edge of LBHC from *D. asper* in parallel arrangements, (c) top face of LBHC from *G. levis* in perpendicular arrangements, and (d) side edge of LBHC from *G. levis* in perpendicular arrangements

For the perpendicular arrangement, *D. asper* gave the highest mean value of 2448 N, followed by *G. levis,* which gave the mean value of 2242 N. The results showed that the type of layer arrangement and the quality of adhesive used affected the screw withdrawal properties of the LBHC. Huseyin *et al.* (2017) found that higher withdrawal resistance perpendicularly occurred to the face of the composites compared to the edge. The surface of parallel arranged samples of LBHC *D. asper* after the screw withdrawal test are illustrated in Fig. 9, where no cracks were detected after test screw withdrawal at the top face of samples and at the side edge of samples. This indicated the importance of the adhesive used to achieve the highest quality bonding with accurate weight and even distribution, which is the groundwork for high-quality bonding. Meanwhile, Fig. 10 illustrates the surface of the perpendicular arrangement of *G. levis* samples after the screw withdrawal test.

Table. 1. Comparison with Other Bamboo Composites

Type of Composites	Matrix	References
Bamboo strips composites	Epoxy	Corradi *et al.* 2009, Lu *et al.* 2013
Bamboo chipboard	Phenol formaldehyde (PF)	Shi and Walker 2006, Siti Suhaily *et al.* 2013
Bamboo Medium Density Fiberboard (MDF)	Urea formaldehyde (UF), Phenol formaldehyde (PF), Isocyanate binder.	Lee *et al.* 2006, Li (2004)
Bamboo mat veneer composites (BMVC)	Polypropylene	Shah *et al.* 2012
Laminated Bamboo Lumber (LBL)	Epoxy	Verma and Chariar 2012, Lee *et al.* 2012
PlyBamboo	Phenol formaldehyde (PF)	Mahdavi *et al.* 2012

Many researchers have reported on various methods to maximize the mechanical properties of bamboo biocomposites, as shown in Table 1. This is important for the bamboo-based biocomposite industry so that the quality of production can be enhanced in line with composites from other materials sources especially wood-based materials. Examples of some of the biocomposite materials found in the market are Bamboo Medium Density Fiberboard (MDF), Bamboo mat veneer composites (BMVC), and Laminated Bamboo Lumber (LBL), which have been widely used in manufacturing, furniture, other products. The special features of bamboo fiber could enhance the flexural, tensile strength, ductility, resistance, *etc*., of the biocomposite (Siti Suhaily *et al.* 2017).

Fracture Surface Morphology

SEM micrographs of the cross-sections of the fractured surfaces of the LBHC are shown in Fig. 10. Figure 10a shows the SEM images of glue line between bamboo strips and OPT veneer. Most of the adhesives observed in bamboo strips filled up the lumen and showed that the adhesive fills up the parenchyma of the bamboo strips and probably improved the bond between the surfaces of the LBHC. As observed, there was some cracking between the bamboo surfaces on side edge, which occurred due to the weak adhesion between bamboo and OPT veneer (Fig 10b). The bamboo fibers were well packed within the available space in the composite, and some glue was capable of penetrating through the vessel lumen adjacent to the glue line. This probably occurred during the glue spreading and the adhesive could fill up the looming void surface by using glue, which then improved the adhesion. The adhesives also were seen to penetrate between bamboo strips and OPT veneer.

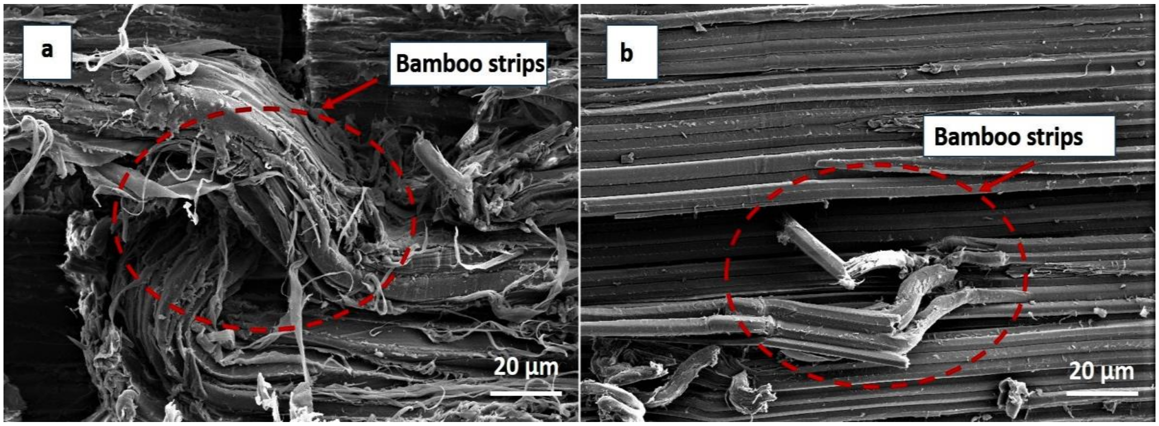

Fig. 10. SEM micrographs of the longitudinal section of the fractured surfaces of LBHC

CONCLUSIONS

In the present study, an attempt was made to develop a wood-like material from a non-wood source to meet the increasing demand of wood-based materials without exploiting forest resources. Bamboo (*G. levis* and *D. asper*) and OPTV sheets were used to produce 5-layer laminates arranged either in parallel or perpendicular layers using urea formaldehyde adhesive. The following conclusions resulted:

1. The *D. asper* bamboo showed optimum results in flexural strength in parallel arrangements, while *G. levis* showed optimum results in screw withdrawal strength in perpendicular arrangements.
2. Based on the above finding, it can be concluded the LBHC has a high potential to replace wood material because of its excellent properties through the laminated hybrid.

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