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Effect of Different Bamboo Species on The Properties of Plybamboo

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Abstract

Aim of study: This study aimed to evaluate the bonding, mechanical, physical and finishing performance of 3-layer plybamboo.

Area of study: The study was conducted under laboratory conditions using bamboo culms harvested from FRIM, Malaysia.

Material and method: Two Malaysian bamboo species; *Gigantochloa levis* (beting) and *Gigantochloa scortechinii* (semantan) were used to fabricate the plybamboo. Urea-formaldehyde (UF) adhesive was used as the bonding medium.

Main results: The results showed that the shear bond strength of plybamboo from *G. scortechinii* was greater than *G. levis* when tested in dry condition, but was inversed when tested after the 24 hours' water immersion test. The modulus of rupture (MOR) and modulus of elasticity (MOE) of plybamboo from *G. levis* and *G. scortechinii* were 103.43, 14001 N/mm^2 and 123.56, 18703 N/mm^2, while the compression-shear strength was 47.97 and 53.16 N/mm^2 respectively. Meanwhile, plybamboo made from *G. scortechinii* had higher thickness swelling (9.68%), linear expansion perpendicular to grain (1.13%) and water absorption (26.51%) than those from *G. levis*. The finishing performance of plybamboo from both species ranges from moderate to good.

Research highlights: Generally, the plybamboo produced from *G. scortechinii* using UF resin showed better shear bond strength, mechanical, physical and finishing performance compared to *G. levis*.

Keywords: Plybamboo, Urea Formaldehyde, Static Bending, Shear Bond Strength, Finishing Performance

Farklı Bambu Türlerinin Plybamboo Özellikleri Üzerindeki Etkisi

Öz

Çalışmanın amacı: Bu çalışmanın amacı, 3 katmanlı plybamboo'nun yapışma, mekanik, fiziksel ve yüzey bitirme performansını değerlendirmektir.

Çalışma alanı: Araştırma, FRIM'den temin edilen bambu materyali kullanılarak laboratuvar koşullarında yürütülmüştür.

Materyal ve yöntem: Plybamboo üretiminde iki Malezya bambu türü, *Gigantochloa levis* (beting) ve *Gigantochloa scortechinii* (semantan), kullanılmıştır. Bağlayıcı madde olarak üre-formaldehit (UF) tutkalı kullanılmıştır.

Temel sonuçlar: Kuru koşullarda *G. scortechinii*'den elde edilen plybamboo'nun yapışma kayma direncinin *G. levis*'e göre daha yüksek olduğunu, ancak 24 saatlik suya daldırma testinden sonra bu durumun tersine döndüğünü göstermiştir. *G. levis* ve *G. scortechinii*'den üretilen plybamboo'nun MOR ve MOE değerleri sırasıyla 103.43 ve 14001 N/mm² ile 123.56 ve 18703 N/mm², basınç-kayma direnci değerleri ise 47.97 ve 53.16 N/mm² olarak belirlenmiştir. Ayrıca, *G. scortechinii*'den üretilen plybamboo'nun kalınlık artışı, liflere dik doğrultudaki doğrusal genişleme ve su alma oranı daha yüksek bulunmuştur. Her iki türden elde edilen plybamboo'nun yüzey bitirme performansının orta ile iyi arasında değiştiği saptanmıştır.

Araştırma vurguları: Genel olarak, UF reçinesi kullanılarak *G. scortechinii*'den üretilen plybamboo'nun, *G. levis*'ten üretilene kıyasla yapışma kayma direnci, mekanik, fiziksel ve yüzey bitirme performansı bakımından daha iyi sonuçlar verdiği belirlenmiştir.

Anahtar kelimeler: Plybamboo, Üre Formaldehit, Statik Eğilme, Yapışma Kayma Direnci, Yüzey Bitirme Performansı

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Introduction

Bamboo has been recognized as a valuable natural resource with enormous potential (Luan et al., 2023). Based on data from the Forestry Department of Peninsular Malaysia (2021), there are seven genera of bamboo in Peninsular Malaysia, specifically *Bambusa, Dendrocalamus, Dinochloa, Racemobamboos, Schizostachyum, Thyrsostachys* and *Gigantochloa*. Among more than 50 indigenous species found in Malaysia, there are only 13 species commercially utilized (Nordahlia et al., 2012). Bamboo is regarded as a rapidly growing plant species and has excellent mechanical properties (Nordahlia et al., 2012). It can act as an alternative source of raw material to wood and a good resource for the production of bamboo-based composites, including bamboo scrimber, bamboo-fiber-reinforced polymer, and plybamboo (Liang et al., 2021). Most of the bamboo composite is widely used in the production of furniture, flooring, construction components, etc. (Rahman et al., 2012; Meng et al., 2016).

The production of plybamboo involves the splitting of bamboo culm, planing of the surface of the bamboo splits, further processing (bleaching), laminated and finally pressed into targeted sizes and shapes (Sharma et al., 2020). Furthermore, the plies of the bamboo were assembled with each layer has grain orientation perpendicular to the next layer to form a plybamboo panel. Urea formaldehyde (UF), melamine urea formaldehyde (MUF) and phenol formaldehyde (PF) adhesives are usually used as the binder in the fabrication of plybamboo (Anwar et al., 2012; Fadhlia et al., 2017). The predominantly used adhesives are amino, phenolic and isocyanate, which 95% of them are formaldehyde-based, and UF being the most commonly used (Bekhta et al., 2021; Alia Syahirah et al., 2023).

The determination of physical properties of plybamboo are important because it is related to the performance and quality of the final products. Some of the bamboo species have been reported to have good mechanical properties and dimensional stability when processed into bamboo composites, enabling their use across multiple applications. However, the variations in the physical properties of different bamboo species could affect the manufacturing processes and its performance as a finished product (Hisham et al., 2006; Xie et al., 2014; Nkeuwa et al., 2022). An example of one of the influencing properties is density, which plays an essential part in producing good quality bamboo composites (Yu et al., 2015). According to Zhang et al. (2021), the density of bamboo is considered to be a significant criterion in improving the mechanical properties and dimensional stability, as well as the serviceability of the bamboo composite product. In a study by Xie et al. (2016), it was mentioned that the higher density of bamboo composite resulted in the improvement of its dimensional stability and mechanical strength.

Other than physical and mechanical properties, the surface quality of bamboo composites needs to be considered in the fabrication of engineered bamboo products, specifically the finishing process. Without the proper finishing, engineered bamboo may be susceptible to various degradation variables, including moisture, ultraviolet (UV) radiation, fungi and pests (Kelkar et al., 2023). Proper finishing process will enhance the durability and longevity of bamboo products by providing a protective barrier against those degradation agents. The finishes ensure that the bamboo products retain their strength and appearance over time. Moreover, the finishing process will improve the smoothness and surface quality of the bamboo, making it visually pleasing and comfortable to touch. Suitable finishes will also contribute to the preservation of the natural color and grain pattern of the bamboo, adding to its overall beauty.

Therefore, the research on plybamboo manufactured from different bamboo species is necessary. The evaluation of their performance in accordance to standard testing methods is needed to ensure that the produced bamboo composite meets the standard requirements, especially for bonding properties. The objective of this study is to evaluate the mechanical, shear bond strength, physical and finishing performance of plybamboo produced from two different bamboo species namely, *G. levis* (beting) and *G. scortechinii* (semantan), with UF adhesive as the bonding medium. The mode of failure of the plybamboo was also determined immediately after the end of the mechanical tests.

Material and Methods

Two Malaysian bamboo species, *G. levis* (beting) and *G. scortechinii* (semantan), were applied in the fabrication of plybamboo samples. The bamboo culms were harvested from the bamboo plantation at the Forest Research Institute Malaysia (FRIM), Kepong, Selangor, Malaysia. Mature culms aged over three years were selected for harvesting. Each of the bamboo culms was cut into 3 parts, each 4m in length. Boric acid was used for preservation treatment of the bamboo. Polyvinyl acetate (PVAc) and UF resin were used as bonding medium of the plybamboo.

Fabrication of Plybamboo

The fabrication of 3-layer plybamboo is shown in Figure 1. Bamboo culms were processed into splits before being treated via immersion method with 2% boric acid solution for 2 weeks. The treated bamboo splits were then conditioned in a kiln-dryer until they reached moisture content (MC) of 12 ± 3%. To produce bamboo strips, the treated bamboo splits were cut to a length of 350 mm, before being planed to 4 mm thick and 20 mm width. PVAc adhesive was used to bond the edge of the bamboo surface and 16 bamboo strips were used to produce a ply of bamboo laminae. Three layers of bamboo laminae were laminated together, with the opposite grain arranged between the layers (perpendicular to the grain), using UF adhesive with 200 g/m^2 glue spread rate. The UF adhesive has a viscosity of 130 and a pH of 8.20 at 30°C. In the laminating process, initial pressure of 5 kg/cm^2 was applied to the 3-layer plybamboo for 15 min. Then, further pressure at 14 kg/cm^2 was applied using a hot press at 110 ºC for another 15 min to produce a 3-layer plybamboo of 12 mm final thickness. The plybamboo was later conditioned at temperature of 23 ± 2 ºC and 50 ± 5% relative humidity (12% EMC) before further tests were conducted.

(a) Harvesting process of *G. levis* bamboo
(b) Treatment of bamboo splits
(c) Drying process of treated bamboo splits
(d) Edge gluing of bamboo strips using PVAc adhesive
(e) Clamping of bamboo strips after edge glued
(f) Application of resin on the surface of bamboo laminae using UF adhesive
(g) Cold press process
(h) Hot press process
(i) 3-layer plybamboo

Figure 1(a-i). Fabrication of 3-layer plybamboo

Evaluation of Bonding Properties

In the bonding shear test, 10 replicates with nominal size of 12 mm thick, 25 mm width and 50 mm length were cut from the plybamboo. The bonding quality of the plybamboo was determined in accordance with the requirements of Malaysian Standard MS 2693:2020, which adopts the normative test methods specified in ISO 12466-1 and ISO 12466-2. Each test sample was measured for its dimensions prior to the bonding shear test. The samples were tested in dry and wet conditions. In the wet condition, samples were immersed in water for 24 h before being tested. The shear test was conducted using Shimadzu Universal Testing Machine at a constant loading rate of 7 mm/min. The application of bonding shear test is shown in Figure 2. The determination of bamboo fibre failure percentage was calculated based on the ratio of the failed bamboo fibre area (excluding failed glue area) and the total tested surface area.

Figure 2. Application of bond shear test on plybamboo

Evaluation of Mechanical Properties

The bending stiffness (MOE) and strength (MOR) were evaluated using three-point static bending test. Samples measuring 12 mm thick, 25 mm width and 300 mm length were used in accordance with ASTM D 1037-96a for wood-based structural panels. Shimadzu Universal Testing Machine was used and a load was applied at a constant rate of 3500 N/min, after which the MOR and MOE of the samples were subsequently measured. The failure mode of the samples was evaluated immediately after the bending test. In the compression-shear strength test, samples with the nominal size of 12 mm thick, 50 mm width and 60 mm length were placed in a vertical position between two parallel metal plates. A constant load was introduced at the top of the samples at a rate of 6.5 mm/min.

Determination of Physical Properties

The moisture content (MC) of the samples was determined by oven-drying at 103 ± 2 ºC until a constant weight was achieved. The initial and final oven-dried weights of each sample were recorded, and the MC was calculated accordingly. The dimensions and weight of the air-dry samples were measured, and their air-dry density was calculated. Dimensional stability was evaluated by measuring the thickness and weight of the samples before and after immersion in distilled water at 25 ºC for 24 h. Thickness swelling, linear expansion (parallel and perpendicular to the grain), and water absorption of the plybamboo were calculated following ASTM D 1037-96a (1996).

Evaluation of Finishing Performance

The plybamboo samples were prepared for testing by cutting them into 10 mm thickness, 100 mm width, and 300 mm length. Prior to the test, all the samples were sanded along the grain using sandpaper with progressively finer grits: 180, 240 and finally 320, to achieve a smooth surface. Subsequently, a spray gun was used to apply the selected lacquer coating onto the plybamboo surface at room temperature. The types of coatings used in this study were nitrocellulose (NC), acid-catalyst (AC) and polyurethane (PU). The finishing systems employed for each type of coating is indicated in Table 1. Three replicates were prepared for each system to ensure reliability. Following coating application, the samples were conditioned at room temperature for one week. Afterwards, they were further conditioned in a controlled environment room with a temperature of 25 °C and relative humidity of 55 % before being tested. The adhesion strength of the finished surface was evaluated using a cross-cut and a pull-off instrument, while the impact resistance was determined through an impact test.

Table 1. Number of sealer and top coat layers for NC, AC and PU according to four different types of finishing systems

Finishing system	Nitrocellulose (NC)		Acid catalyst (AC)		Polyurethane (PU)	
	*Sealer	*Top coat	*Sealer	*Top coat	*Sealer	*Top coat
1	1	1	1	1	1	1
2	1	2	1	2	1	2
3	2	1	2	1	2	1
4	2	2	2	2	2	2

Notes: *Number of layers

Adhesion Test

The adhesion test was conducted through cross-cut method, following the guidelines of MS 133-E6:2010. The coated surface was subjected to parallel cuts in the form of a lattice pattern using a cross hatch cutter. Each lattice pattern comprised of six cuts, creating a 2 mm square spacing between each cut in both directions. Subsequently, a strip of pressure-sensitive adhesive tape was applied over the lattice and later removed after 5-minute application. The percentage of the cut area was assessed based on the classification provided in the standard.

Pull-off Test for Adhesion

In the pull-off test for adhesion, a test dolly was adhered to the surface of the coated sample, and then placed in a conditioned room for a duration of 24 hours. The test was performed utilizing a pull-off adhesion tester on both single-coat and multi-coat systems of the samples. The adhesion strength characteristics were assessed and the occurrence of surface failure was evaluated in accordance with the guidelines outlined in MS 133-E10:2012.

Impact Test

In the impact test, a steel ball was dropped from a height of 2.0 ± 0.01 m onto the surface of the test sample. The appearance of the test sample after impact by the steel ball was assessed. The indentation of the impacted region was inspected and rated based on the assessment code in MS 1215-6:2012.

Statistical Analysis

Data collected from each test were statistically analyzed using analysis of variance (ANOVA) of Statistical Analysis Software (SAS 9.4). The least significant difference (LSD) test was conducted to determine whether the differences in means within and between different groups were statistically significant at 95% confidence level. In this study, the means having differences above the LSD value were assigned with different letter(s), e.g. a, b, c. Thus, the means assigned with the same letter were not significantly different at $p \leq 0.05$.

Results and Discussion

Shear Strength and Bamboo Fibre Failure Percentage

Bonding qualities have a considerable impact on the quality of wood and non-wood based product (Anwar et al., 2012). In order to determine the bonding quality of plybamboo, shear bond test was conducted and the failure was observed. Mean values for shear bond strength and the percentage of bamboo fiber failure are summarized in Table 2. The image profiles of the bamboo failure were shown in Figure 3. The mean value of the dry shear bond strength of *G. levis* plybamboo samples is slightly lower than *G. scortechinii* samples but not significantly different (at 95% significant level) when tested with ANOVA. However, the mean value of shear bond strength of plybamboo samples from *G. levis* is higher than *G. scortechinii* after 24 h of water soak conditioning.

Table 2. Mean shear bond strength and bamboo fiber failure percentages for *G. levis* and *G. scortechinii* plybamboo

Pre-treatment	*G. levis*		*G. scortechinii*	
	Shear strength (N/mm^2)	Bamboo failure (%)	Shear strength (N/mm^2)	Bamboo failure (%)
Dry	2.36[a]	26.15	2.81[a]	75.00
	(0.20)	(19.81)	(0.43)	(13.04)
Soak 24 h	2.02[a]	35.83	1.69[b]	54.00
	(0.48)	(11.64)	(0.46)	(19.21)

Notes: Values in parentheses represent standard deviations. Means followed by the same letters ([a, b]) in the same row are not significantly different at $p \leq 0.05$ according to the LSD test

The results showed that the mean values of shear bond strength of plybamboo samples from *G. scortechinii* soaked in water for 24 h are significantly lower than the samples in dry condition. This could be due to alterations in dimensional stability, with cell walls expanding or shrinking as moisture levels fluctuate. Attributed to the water absorption by the sample, the hydrogen bonds between the bamboo and adhesive are disrupted, resulting in the decrease of shear bond strength (Guan et al., 2014). Anwar et al. (2012) found similar conclusion, indicating that the reduction in shear bond strength was due to the extensive stress created along the glue-line, where different rates of swelling occurred in the water soak test. Therefore, the sample tends to fail easily due to the release of internal stresses.

High bamboo fibre failure percentage was observed on the *G. scortechinii* plybamboo samples tested in dry condition (75.00%) and after 24 h of water soak (54.00%). In comparison, the bamboo fibre failure percentage of *G. levis* plybamboo samples were 26.15% and 35.83% for dry and 24 h of water soak conditions, respectively. Visual observation (Figure 3) shows a thin layer of bamboo fibres on the sheared surface of *G. levis* plybamboo, in contrast to *G. scortechinii* which showed higher making the percent of *G. levis* plybamboo lower. The results showed that all the plybamboo samples achieved the minimum shear strength as required by Malaysian Standard MS 2693:2020.

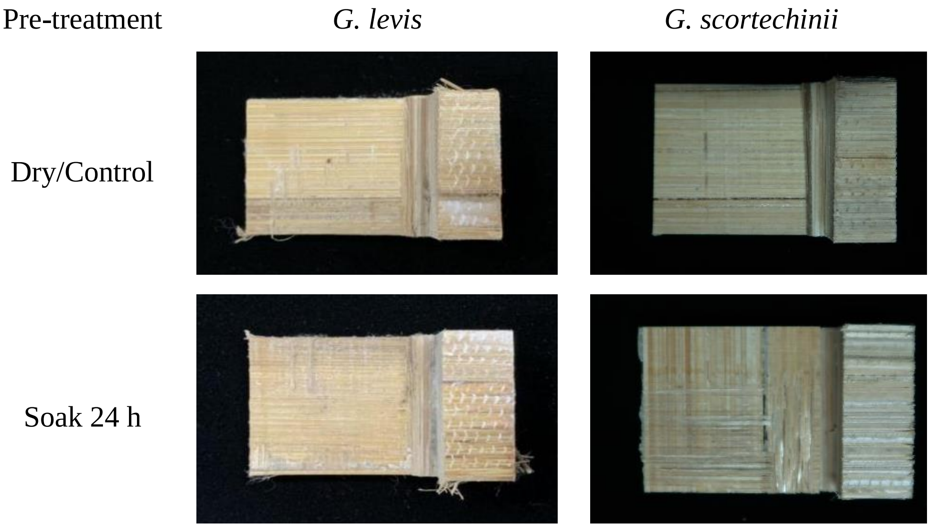

Figure 3. Areas of bamboo fibre failure after shear bond strength test

Mechanical Properties

The mean values of moisture content, density and mechanical properties of plybamboo samples are presented in Table 3. The mean MC and density of *G. levis* plybamboo were 12.32% and 741.21 kg/m^3, respectively. These values were slightly lower than mean MC (12.60%) and density (766.15 kg/m^3) of *G. scortechinii* plybamboo. The plybamboo from *G. levis* showed significantly lower MOR (103.43 N/mm^2), MOE (14001 N/mm^2) and compression-shear strength (47.97 N/mm^2) compared to *G. scortechinii* plybamboo with MOR (123.56 N/mm^2), MOE (18703 N/mm^2) and compression-shear strength (53.16 N/mm^2).

Nordahlia et al. (2019) conducted a study to investigate the mechanical properties of *G. scortechinii* and *G. levis* in split form. The study found that the mechanical properties of split bamboo from *G. levis* were higher than those from *G. scortechinii*. In contrast, this study found that the mechanical properties of plybamboo manufactured from *G. scortechinii* were higher than those of *G. levis*. These results vary due to the different forms of bamboo used. Splits bamboo, with no modifications, differs from engineered or composite bamboo, such as plybamboo. The mechanical properties of plybamboo are affected by many factors such as the type of glue for lamination, pressure applied, glue spread rate, presence of nodes and laminate orientation (Anokye et al., 2016). The findings show that the mechanical properties of bamboo can differ significantly based on its form or end-use product (Asniza et al., 2023).

Table 3. Mechanical properties of *G. levis* and *G. scortechinii* plybamboo

Species	MC (%)	Density (kg/m^3)	Mechanical properties (N/mm^2)		
			MOR	MOE	Compression-shear strength parallel to grain
G. levis	12.32^a	741.21^a	103.43^a	14001^a	47.97^a
	(1.60)	(19.23)	(15.75)	(2564)	(4.56)
G. scortechinii	12.60^a	766.15^a	123.56^b	18703^b	53.16^b
	(1.90)	(15.44)	(16.35)	(2412)	(2.86)

Values in parentheses represent standard deviations. Means followed by the same letters ($^{a, b}$) in the same row are not significantly different at $p \leq 0.05$ according to the LSD test

Physical Properties

The findings on the dimensional stability of plybamboo produced from *G. levis* and *G. scortechinii* are shown in Table 4. *G. levis* plybamboo exhibited significantly lower thickness swelling (5.70%), linear expansion perpendicular to grain (0.47%) and water absorption (22.15%) than those from *G. scortechinii*. Meanwhile, the linear expansion parallel to grain of plybamboo made from *G. scortechinii* (0.39%) showed lower mean value compared to *G. levis* (0.52%) after 24 h of water soaking.

Table 4. Physical properties of *G. levis* and *G. scortechinii* plybamboo

Species	Thickness swelling (%)	Linear expansion parallel to grain (%)	Linear expansion perpendicular to grain (%)	Water absorption (%)
G. levis	5.70^b	0.52^a	0.47^b	22.15^b
	(1.12)	(0.59)	(0.18)	(2.94)
G. scortechinii	9.68^a	0.39^b	1.13^a	26.51^a
	(1.63)	(0.63)	(0.54)	(2.10)

Values in parentheses represent standard deviations. Means followed by the same letters ($^{a, b}$) in the same row are not significantly different at $p \leq 0.05$ according to the LSD test

The findings indicated that the plybamboo manufactured from *G. levis* was dimensionally stable than *G. scortechinii* plybamboo. The differences in the physical properties between these two species can be associated to a variety of factors, including the different swelling-shrinkage properties of the respective species, processing conditions and density variations. Meanwhile, the changes in linear expansion parallel and perpendicular to the grain could be attributed from the variations of MC from the plybamboo (Guo et al., 2003).

According to Nugroho and Ando (2001), the thickness swelling of bamboo will increase with the increase in board density. Typically, high density bamboo has greater spring-back, especially in the compacted layers of high density plybamboo. With the accumulation of the stresses created during the pressing stage of the plybamboo fabrication, it is expected that the plybamboo will expand significantly when exposed to water. This could be the main cause of the higher thickness swelling of *G. scortechinii* plybamboo, which has higher density compared to *G. levis* plybamboo.

Furthermore, Anwar (2008) stated that the reduced thickness swelling, linear expansion perpendicular to grain and water absorption of *G. levis* plybamboo could be resulted from the better penetration of UF into the lower density bamboo during fabrication of the plybamboo. The adhesive penetration behavior within the parenchyma cell has increased the dimensional stability of the plybamboo. The increase in the amount of adhesive being used to bond the layers will contribute to the deeper penetration into the parenchyma. The cured adhesive will become an infusible substance that protects the plybamboo against moisture.

Finishing Performance

The adhesion behavior is influenced by the finishing system that provides a good wetting and clean surface (Tracton, 2005). The coating adhesion on the bamboo surface is essential for ensuring the longevity, protection, aesthetic appeal, and ease of maintenance of the bamboo products (Guo et al., 2023). A strong bond between the finish and the bamboo surface contributes to the overall performance and quality of the finished product, enabling it to withstand environmental challenges and maintaining its visual appeal for an extended period.

Table 5 presents the adhesion ratings obtained from the cross-cut test conducted on *G. levis* and *G. scortechinii* plybamboo. The affected area of the cross-cut on both *G. levis* and *G. scortechinii* plybamboo did not exceed 5%. The PU finishing system applied to the *G. levis* plybamboo exhibited excellent adhesion properties, as evidenced by the adhesion rating of 0, indicating no removal of the coating in any area. Overall, both bamboo species demonstrated favorable adhesion properties, with all the finishing systems achieving adhesion ratings of either 0 or 1. Furthermore, the findings indicated that a strong bond between the coating and substrate can be achieved without consideration of the bamboo species used in the production of plybamboo.

Table 5. Adhesion rating based on cross-cut test of plybamboo coated with different finishing systems

Species	*G. levis*			*G. scortechinii*		
Finishing system	*NC	*AC	*PU	*NC	*AC	*PU
1	1	0	0	0	1	1
2	1	1	0	1	1	1
3	1	0	0	1	1	1
4	1	1	0	1	1	1

Notes: *Rating 0 to 5, where 0 is very good and 5 very poor

In addition to the cross-cut test, the pull-off test for adhesion represents another significant adhesion assessment method. Similar findings were observed in the pull-off test for adhesion (Table 6), indicating a strong bond between the coating and substrate. This observation emphasizes the influence of the type of finish utilized in the finishing system. The highest recorded pull-off strength value was 4.14 N/mm^2 for finishing system 4 (AC coating on *G. scortechinii* plybamboo), whereas the lowest value was 2.36 N/mm^2 for finishing system 3 (NC coating on *G. scortechinii* plybamboo). Overall, more than 70% of the coated plybamboo samples demonstrated a pull-off strength exceeding 3.00 N/mm^2.

Table 6. Pull-off strength results of *G. levis* and *G. scortechinii* plybamboo coated with different finishing systems and coatings

Species	*G. levis*			*G. scortechinii*		
Finishing system	*NC	*AC	*PU	*NC	*AC	*PU
1	2.99 (A/B)	3.44 (A/B)	2.67 (A/B)	3.11 (A/B)	3.09 (A/B)	3.57 (B/C)
2	3.54 (n/m)	3.05 (n/m)	2.59 (A/B)	3.39 (A/B)	3.44 (n/m)	2.83 (n/m)
3	3.51 (A/B)	3.76 (n/m)	3.33 (n/m)	2.36 (n/m)	3.87 (n/m)	3.71 (n/m)
4	3.48 (A/B)	3.49 (A/B)	2.75 (n/m)	2.86 (n/m)	4.14 (n/m)	3.52 (n/m)

Notes: * Values in N/mm·

The impact resistance ratings of various finishing systems and finishes are presented in Table 7. Impact resistance testing was conducted to assess the ability of the coatings to withstand deformation and cracking when subjected to sudden high physical loads on the surface of the coated plybamboo. The impact resistance ratings for both *G. levis* and *G. scortechinii* plybamboo samples (across all finishing systems) were rated as good, ranging from 3 to 4. It was observed that more than 45% of the plybamboo samples received a rating of 3. The brittleness of a coating refers to its tendency to crack under impact when it fails to deform in response to mechanical stress. In thin films, the detachment area or cracks are concentrated in the impact zone, while thicker films are less affected by the impact, allowing most coatings to pass the test (Tracton, 2005; Goglio & Rossetto, 2008). Despite the use of different bamboo species to produce plybamboo with results indicating no significant differences in the performance of the various finishing systems, as the overall results demonstrated high impact strength values.

Table 7. Impact resistance ratings of plybamboo coated with different finishing systems

Species	*G. levis*			*G. scortechinii*		
Finishing system	*NC	*AC	*PU	*NC	*AC	*PU
1	4	4	3	4	3	3
2	4	4	3	4	4	3
3	4	4	4	4	3	3
4	3	4	3	3	4	3

Notes: *Rating 1 to 5, where 5 is very good and 1 very poor

Conclusion

The present study suggests that UF adhesive showed good performance as bonding medium for plybamboo produced from *G. levis* (beting) and *G. scortechinii* (semantan) bamboo species. The results also indicated that the plybamboo made from *G. levis* and *G. scortechinii* have satisfactory mechanical, shear bond strength, physical, and finishing performance with all the tested samples met the respective minimum standard requirements. Furthermore, the finishing performance of the coated plybamboo samples showed moderate to good ratings in the cross-cut test and impact resistance test. In conclusion, the test results of the plybamboo manufactured from *G. levis* and *G. scortechinii* can be used as a reference in developing new standards for manufacturing and testing of plybamboo produced from different bamboo species.

Ethics Committee Approval

N/A

Peer-review

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Author Contributions

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Conflict of Interest

The authors declare that they have no conflict of interest.

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