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SHEAR AND BENDING PERFORMANCE OF HORIZONTAL LAMINATED BAMBOO LUMBER BONDED WITH *UREA-FORMALDEHYDE* AND PRESERVED WITH *DELTAMETHRIN*

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Graphical abstract

Abstract

Deltamethrin has potential to be used for bamboo strip preservation in laminated bamboo lumber (LBL) beam industry. However, there is a lack of information regarding the effect of deltamethrin preservation on the structural performance of the LBL beam. This study was intended to observe shear and bending performance of LBL beam made of *Dendrocalamus asper*, preserved by *deltamethrin*, and glued by *urea-formaldehyde*. The adhesive bonding strength test following ASTM D905 and MD Block method and static bending test based on ASTM D143 were performed toward preserved and unpreserved samples. The performance was observed by calculating adhesive bonding strength, *MOE*, *MOR*, ductility index, and investigating failure modes. The results show that the average adhesive bonding strength of the treated sample is 7.28 MPa (ASTM D905) and 7.03 MPa (MD Block), while the average adhesive bonding strength of the untreated sample is 7.67 MPa (ASTM D905) and 7.41 MPa (MD Block). The average *MOE* (modulus of elasticity) and *MOR* (modulus of rupture) of the treated specimen is 18,840 MPa and 110 MPa, respectively. The untreated specimen's average *MOE* and *MOR* are 18,199 MPa and 109 MPa, respectively. The average ductility index of untreated and treated specimens is 4.8 and 3.9, respectively. The adhesive bonding strength of treated and untreated samples are higher than the bamboo shear strength. The result indicates that deltamethrin has no significant effect on the adhesive bonding strength, *MOR*, and *MOE* of the LBL beam. The LBL beams show significant plastic deformation before final beam failure.

Keywords: Laminated bamboo lumber, adhesive bonding strength, bending performance, *deltamethrin, urea-formaldehyde*

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1.0 INTRODUCTION

Bamboo is a renewable and multifunction resource considered a timber alternative for construction materials [1]. It is a fast-growing plant that can be harvested for construction only in 3-7 years [2]. As a construction material, bamboo has excellence in its weight to strength ratio that ranges from 0.55 – 0.77 [3]. The compression strength of bamboo is two times of normal concrete, and the tensile strength of bamboo is close to steel [4]–[6]. In Indonesia, Dendrocalamus asper bamboo species is widely used as the construction material because it has an adequate thickness and diameter [7]. The use of bamboo was limited due to its uneven cylindrical shape, encouraging researchers to develop an innovation to optimize bamboo usage [8], [9], [10].

Adopting the glued lamination technology [11], [12], the application of laminated technology on the bamboo culm yield an engineered bamboo product known as laminated bamboo lumber. It has better mechanical properties and various shapes compared to bamboo culm [13]. LBL beams were manufactured by glueing several bamboo strips in a specific arrangement. The compatibility between bamboo and the adhesive will determine the quality of adhesive bonding. *Urea-formaldehyde* is one of the adhesives commonly used because of its affordable price, inconspicuous colour, quick-drying characteristics, and good bonding performance [14], [15]. Nonetheless, the excellent performance of the LBL beam must be accompanied by sufficient durability to prevent the fungal and insect attack that results in a longer bamboo's service life.

The previous research results conducted by Tirana et al. (2021) and Azmy et al. (2021) depict that 0.01% deltamethrin solution is a suitable insecticide that can be used as bamboo strip preservatives before being manufactured as an LBL beam [16], [17] . According to Ross et al. (2000), the chemicals contained in the preserved bamboo strip can interact with adhesive and decrease its bonding strength [18]. Novitri (2021) conducted urea formaldehyde glue line shear test and LBL bending test. Bamboo strips were preserved using deltamethrin [16]. However, the research results were only limited to inform the glue line shear strength, modulus of elasticity (MOE), and modulus of rupture (MOR). Thus, this research aims to conduct the comprehensive study on the shear and bending performance of the LBL beam glued using urea-formaldehyde and preserved using 0.01% deltamethrin. Failures occurred on the adhesive bonding test and static bending test were observed. Then, besides calculating adhesive bonding strength, MOE, and MOR, the ductility index of LBL beam was analyzed in this research. The adhesive bonding specimen was tested according to ASTM D905 and MD block method [18]. The LBL beam static bending test was conducted based on ASTM D905.

2.0 METHODOLOGY

Specimens Preparation

This research utilized 3-5 years of Dendrocalamus asper bamboo, harvested from Purworejo Bamboo Forestry, Central Java. Only the bottom to the middle part of bamboo was used in this research. The length of the bamboo culm is 6 m, and its diameter ranges from 9 to 12 cm. To produce LBL beam, the bamboo strips were bonded using *urea-formaldehyde*, an adhesive commonly used for interior-grade plywood. This adhesive consists of UA-125, flour, and Catalyst HU-12 with a proportion of 100:20:0.3. The manufacturing process of glued laminated bamboo is clearly described in Figure 1.

The bamboo culms (Figure 1.(a)) were cut into two pieces (Figure 1.(b)) and marked to distinguish its top-middle and middle-bottom parts. Furthermore, the bamboos were split to produce bamboo strips that have 20 – 30 mm of width (Figure 1.(c)). Each bamboo strip's outer and inner skin was removed using a planner machine (Figure 1.(d)) so that they have 5-10 mm of thickness. The bamboo strips were preserved using 0.01% *deltamethrin*, and the cold-immersion method (Figure 1(e)) were applied within 30 minutes. After removing the bamboo strip's skin, the preservation was carried out to maximize the preservatives absorption. The preserved bamboo strips were dried until their moisture content reached 10%-15% (Figure 1.(f)). The adhesive was hand-spread into the bamboo strips on the one-side surface with a spread rate of 300 g/m^2 (Figure 1.(g)). Subsequently, the bamboo strips were vertically arranged to form a 60 – 70 mm thick bamboo board that consisted of 8-10 bamboo strips.

The cold-press process was performed using a hydraulic press machine with a pressure point of 2 MPa (Figure 1.(h)). The stack of bamboo strips was clamped to maintain this pressure (2 MPa) given by the hydraulic press. Then, the hot-press process was started by putting the clamped bamboo strips in the oven with a temperature of 95-105^{o}C within 30 minutes (Figure 1.(i)). The required standing time from the cold-press to the hot-press process is 1-4 hours. It was then kept at room temperature for 24 hours. After that, the clamp was opened, and the bamboo board was formed. Bamboo boards were smoothened, glue-spread on the one-side surface, cold-pressed, clamped, and then hot-pressed using the same method as bamboo strips production to form laminated bamboo lumber (LBL) beam (Figure 1.(j)). Finally, it was cut to get adhesive bonding strength and bending test specimens.

Figure 1. Manufacturing process [13]

Design Specimens and Test Method

Adhesive Bonding Strength Test

The adhesive bonding strength was evaluated using ASTM D905 and MD block method proposed by Derikvand and Pangh (2016) [19]. The evaluation using MD block method was conducted due to error cutting possibility on ASTM D905 specimens. Hence, the shear failure mode and bonding shear strength resulted from both methods were observed and compared in this study.

The ASTM D905 specimens were derived from the same LBL beam used for making the static bending test specimen. Meanwhile, MD block method specimens were made separately from different LBL beams. Figure 2.(a) and 2.(b) show the specimen dimension for each method. The total specimens were 400 and clearly described in Table 1.

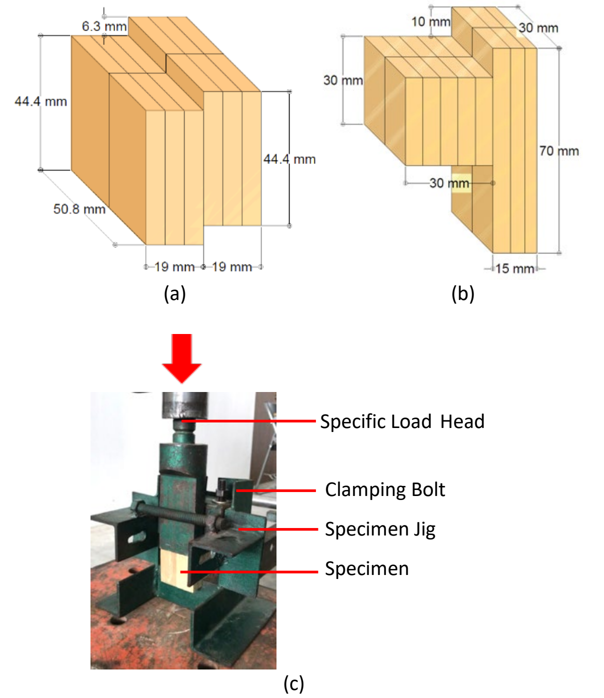


Figure 2. a) Dimesion of ASTM specimen, b) Dimension of MD-block specimen, c) set up of adhesive bonding strength test, units in mm [13]

Table 1. Specimens Tested [13]

Treatment	Static Bending Test	Adhesive Bonding Test	
	ASTM D143	ASTM D905	MD Block Shear
Treated	20	100	100
Untreated	20	100	100
Total	40	200	200

The adhesive bonding strength test setup is shown in Figure 2(c). The applied loading rate of ASTM D905 and MD block specimens were 5mm/min and 1mm/min, respectively. The ultimate load and the failure mode of each specimen were observed. The adhesive bonding strength can be obtained using Equation (1), where τ is the bond shear strength, P is the maximum load, and A refers to the shear area.

$$\tau = \frac{P}{A} \tag{1}$$

Statistical analysis was conducted using Statistical Package for Social Science (SPSS) software. One way analysis of variance (ANOVA) method was conducted at the confidence level of 95% (α = 0.05) to find out the effect of the preservation on the adhesive bonding strength.

Static Bending Test

A static bending test was performed following ASTM D-143. The dimension of the bending test specimen was 50 mm x 50 mm x 760 mm. The number of each treated and untreated specimen was 20, as illustrated in Table 1. The test setup can be seen in Figure 3. The clear span between the two supports was 710 mm. Two Linear Variable Differential Transformers (LVDT) were placed in the midspan to measure displacement. The specimen was continuously loaded under a 2.5 mm/min loading rate until the ultimate load was achieved. The applied load and occurred displacement during the test were recorded. Then, the bending failure modes were observed. The *MOR* and *MOE* of the LBL beam were calculated using Equation (2) and (3), where P is the ultimate load, L is the length between supports, b is the cross-section width, h is the thickness and δ is the elastic displacement.

$$MOR = \frac{3PL}{4bh^2} \tag{2}$$

$$MOE = \frac{PL^3}{4bh^3\delta} \tag{3}$$

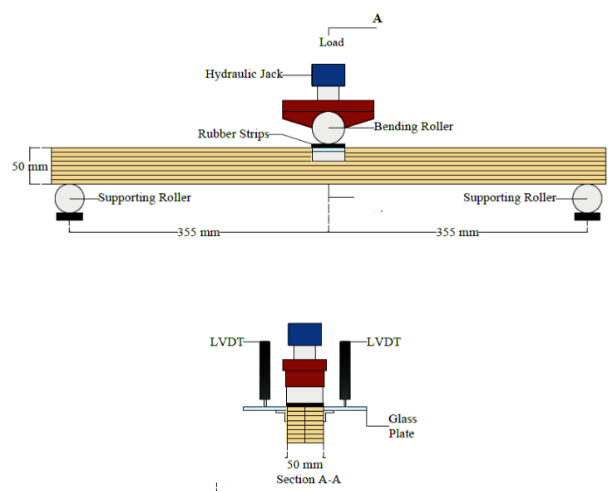
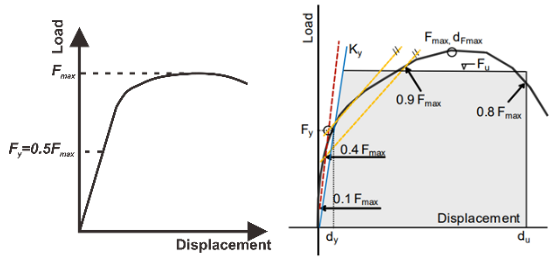


Figure 3. Specimen dimensions and set up of static bending test (units in mm)

Further observation on ductility behavior was conducted by calculating the ductility index value. Ductility represents the ability of a material to deform before running into failure, and it is an important parameter, particularly in earthquake-resistant buildings. The ductility index was determined by dividing the ultimate displacement (Δ_u) by the displacement at yield (Δ_y). $\Delta_u$is the corresponding displacement where the applied load decreases about 20% after the maximum load was achieved. Meanwhile, the yield load (P_y) used to determine $\Delta_y$was calculated using two different methods, that is Karacabeyli & Ceccoti (1996) method and Yasamura & Kawai (1997) method, as described in Figure 4. In the Karacabeyli & Ceccoti (1996) method, P_y was 50% of the P_{max} [20], [21], while in the Yasamura & Kawai (1997) method [19], P_y was obtained from the intersection of the K_{10-40} line and $K_{//40-90}$ line [22].



a) b)

Figure 4. Method for estimating yield load of LBL beam: a) Karacabeyli & Ceccoti (1996) [17], [18], and b).Yasamura & Kawai (1997) [19]

3.0 RESULTS AND DISCUSSION

Adhesive Bonding Strength Test Result

Table 2 shows the resume of the adhesive bonding strength test result conducted in this study. Using ASTM D905 standard test method, the average adhesive bonding strength of the untreated sample (7.67 MPa) is relatively higher than that of the treated sample (7.28 MPa). Similarly, the average adhesive bonding strength resulting from the MD block method is 7.41 MPa and 7.03 MPa for untreated and treated samples, respectively. Preservative treatment causes reduction of adhesive bonding strength by 5%. The ANOVA result indicates that preservative treatment using *deltamethrin* will not affect the adhesive bonding strength of the laminated bamboo beam.

In contrast, using the same adhesive, research conducted by Antwi-Boasiako (2012) shows that preservative treatment using *E.suaveolens* and *CCA* decrease the adhesive bonding strength of LBL beams [14]. As shown in Table 3, the adhesive bonding strength of the sample preserved with *E.suaveolens* and *CCA* is 72% and 38% of the untreated specimens, respectively. As previously described, preservative treatment using *deltamethrin* does not affect the adhesive bonding strength of the LBL beam that bonded with *urea-formaldehyde*. The results show that in either ASTM D905 or MD Block samples, the adhesive bonding strength of the treated specimen is 95% of the untreated specimen. It implies that *deltamethrin* can be used as preservatives in LBL beam production.

Related to the test method, the result of this study was in line with that conducted by Derikvand and Pangh (2016). As shown in Tables 2 and 3, the adhesive bonding strength of the specimen tested following MD Block method is slightly smaller than ASTM D905. Derikvand and Pangh (2016) reported that the ratio of adhesive bonding strength resulted from MD Block test and that from ASTM D905 is 99% [19]. In this research, the ratio of adhesive bonding strength resulted from MD Block method to ASTM D905 reaches 97% for both treated and untreated samples.

For the same bamboo species, the application of *urea-formaldehyde* adhesive and *deltamethrin* preservative produce a higher adhesive bonding strength than that of *polymer-isocyanate* or *PVAc* adhesives and *borax* preservatives (see Table 3, the result reported by Sumawa (2018) and Nugroho (2019)) [23], [24]. Nevertheless, it does not mean that using *PVAc* adhesives and *borax* preservatives surely produces an LBL beam with a lower bonding strength. A further observation is needed considering that the manufactured process of the LBL beam also influenced the bonding strength of adhesive.

The failure mode of adhesive bonding strength test specimens can be seen in Figures 5 to 8. These figures show the failure modes occurred on the lowest, middle, and highest adhesive bonding strength. The failure mode of the untreated specimen with higher adhesive bonding strength was identical to that of the treated specimen with lower strength. A rougher surface and grooves of bamboo fibre was found in the surface plane. This indicates that the adhesive was stronger than the bamboo. In the case of the MD block specimen, even though the treated and untreated sample have a similar failure mode, the grooves of bamboo fibre are more obviously seen at the failure plane of the

a) 3.8 MPa-MN55 b) 7.44 MPa-MN81 c) 10.30 MPa-MN69

Figure 5. glue line shear failure of the MD block sample of the untreated LBL (adhesive bonding strength-sample code)

Table 2. Adhesive Bonding Strength Test Result

Standard Test	Treatment	N	Adhesive Bonding Strength (MPa)			COV (%)	F_{table}	F_{calc}	$Prob$
			Min	Max	Average				
ASTM D905	Treated	100	3.49	10.53	7.28	21.34	3.89	3.45	0.07
	Untreated	100	4.57	10.62	7.67	17.71			
MD Block	Treated	100	3.45	11.07	7.03	24.23			
	Untreated	100	3.80	10.54	7.41	22.08			

Table 3. Adhesive Bonding Strength of LBL Resulted from Previous Researchs

Researcher	Bamboo/ wood species	Adhesive	Preservatives	Standard test	Adhesive bonding strength
Antwi-Boasiko (2012)	*Bambusa vulgaris vulgaris*	*urea- formaldehyde*	- (untreated) *E.suaveolens* *CCA*	EN 13354	3.83 MPa 2.75 MPa 1.45 MPa
Derikvand and Pangh (2016)	Oriental beech wood (*Fagus orientalis L.*)	*urea-formaldehyde*	- (untreated)	ASTM D905 MD block	9.62 MPa 9.54 MPa
Sumawa (2018)	*Dendrocalamus asper*	*Polymer- Isocyanate*	*Borax* (Boucheri-*Mor*isco method) *Borax* (Hot soaking method)	ASTM D905	4.79 MPa 6.57 MPa
Nugroho (2019)	*Dendrocalamus asper*	PVAc	*Borax* (Boucheri-*Mor*isco method) *Borax* (Hot soaking method)	ASTM D905	3.53 MPa 2.79 MPa

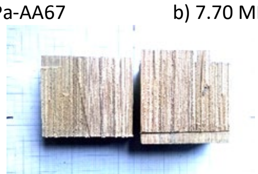
a) 3.45 MPa-MA79 b) 7.08 MPa-MA43 c) 10.47 MPa-MA17

Figure 6. glue line shear failure of the MD block sample of the treated LBL (adhesive bonding strength-sample code)

a) 4.57 MPa-AN66 b) 7.52 MPa-AN59 c) 10.04 MPa-AN43

Figure 7. glue line shear failure of the ASTM D905 sample of the untreated LBL (adhesive bonding strength-sample code)

a) 3.49 MPa-AA67 b) 7.70 MPa-AA83



c) 10.53 MPa-AA25

Figure 8. glue line shear failure of the ASTM D905 sample of the treated LBL (adhesive bonding strength-sample code)

treated sample. In the case of the ASTM D905 specimen, the obvious bamboo fiber can be seen either on the untreated or treated failure plane. It may be caused by the difficulty placing the shear plane of the ASTM D905 specimen precisely located on the glue line.

The rougher failure surface does not correspond to the higher adhesive bonding strength (see the failure mode of the following specimens: MN69 to MN81; MA43 to MA79; AN3 to AN59). It indicates that the adhesive bonding strength of LBL was affected by the heterogeneous strength of the raw bamboo and the gluing process (the adhesive spreading and pressing process). These two factors cause the high *COV* value (>10%) in the adhesive bonding strength test results (see Table 2).

Static Bending Test Result

Failure Modes Of Laminated Bamboo Lumber (LBL) Beams And Load-Deflection Curve

There are six failure modes that occurred during the static bending test, that is simple tension and splintering tension (mode 1); simple tension only (mode 2); splintering tension only (mode 3); horizontal shear due to bamboo failure (mode 4); horizontal shear due to delamination (mode 5); and simple tension and horizontal shear but not delaminated (mode 6). Figures 9 to 14 show the pattern of each failure mode.

Figure 9. Simple tension & splintering tension failure mode

Figure 10. Simple tension failure mode

Figure 11. Splintering tension failure mode

Figure 12. Horizontal shear (bamboo failure) failure mode

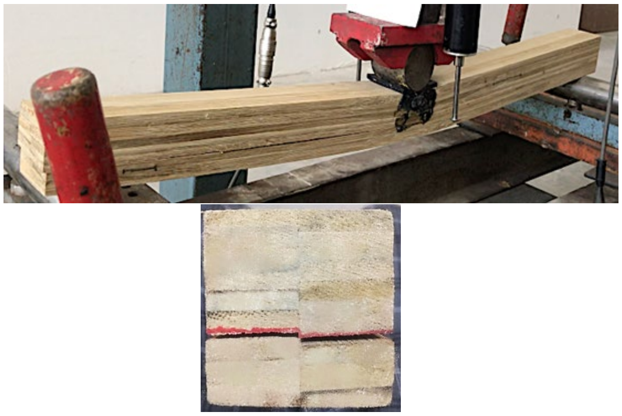


Figure 13. Horizontal shear (delamination) failure mode

Figure 14. Simple tension & Horizontal shear but not delaminated failure mode

The failure modes of treated and untreated LBL beams are presented in Table 4, Table 5, and Figure 15. Only five failure modes were found in the treated specimens, dominated by mode 4. Meanwhile, the failure mode occurred in the untreated specimens encompass all the failure mode types, dominated by mode 2. The treated specimen's maximum load, P_{max}, is 15,640 N, and the maximum deflection at P_{max} is 31.78 mm. The P_{max} of the untreated specimen is 15,123 N, and the maximum deflection at P_{max} is 27.70 mm. The average P_{max} and Δ_{Pmax} for treated specimens reach 13,327 N and 20.98 mm, while for the untreated specimens reach 13,013 N and 21.13 mm, respectively.

As seen in Table 4 and Table 5, for treated specimens, failure mode 3 gives the highest average P_{max} (13,728 N). Moreover, failure mode 2 gives the highest average maximum deflection (Δ_{max}) at 27.19 mm. For untreated specimens, failure mode 6 gives the highest average P_{max} (15,123 N), and failure mode 5 gives the highest average Δ_{max} (31.58 mm). Also, from Figure 15, it can be concluded that the type of failure mode does not correlate with the maximum load and deflection.

The load-deflection curves resulted from each failure mode for the treated and untreated specimens are shown in Figure 15. Figures 15.a and 15.b show that the load-deflection curves between treated and untreated specimens are not significantly different. Considering Figure 15, the P_{max} of all specimens (both treated and untreated) has been reached although the horizontal shear failure mode appears, so that the *MOR* value can be calculated (The *MOR* of the LBL beams will be discussed later).

Figure 15 shows that both treated and untreated LBL beams have a sufficient ductility property. The ductility index of each tested specimen can be seen in Tables 4 and 5. The P_y obtained from the Yasamura & Kawai (1997) method varies from 47% to 97% P_{max} depending on the load-displacement curve pattern of each specimen. Calculation of P_y using Karacabeyli & Ceccoti (1996) method tends to yield a lower P_y than Yasamura & Kawai (1997) method. Thus, the ductility index obtained from the Karacabeyli & Ceccoti (1996) method gives greater values (means the structure is more ductile).

In general, Karacabeyli & Ceccoti (1996) and Yasamura & Kawai (1997) method show similar results regarding the highest and the lowest ductility index values of the LBL beam (see Table 4 and Table 5). The highest and lowest ductility index of the treated LBL beam was achieved by specimens that failed in mode 2 and mode 1, respectively. The lowest ductility index of the untreated LBL beam was found at the specimen that failed at mode 3. For the highest ductility index of the untreated specimens, the two applied methods give a slightly different result. The highest ductility index in Karacabeyli & Ceccoti (1996) methods was found on failure mode 6. However, the Yasamura & Kawai (1997) method shows that failure mode 5 has the highest ductility index. It can be seen that the failure mode containing splintering tension tends to have the lowest ductility index, both in the treated and untreated specimens. Furthermore, Figure 15 shows that the type of failure mode does

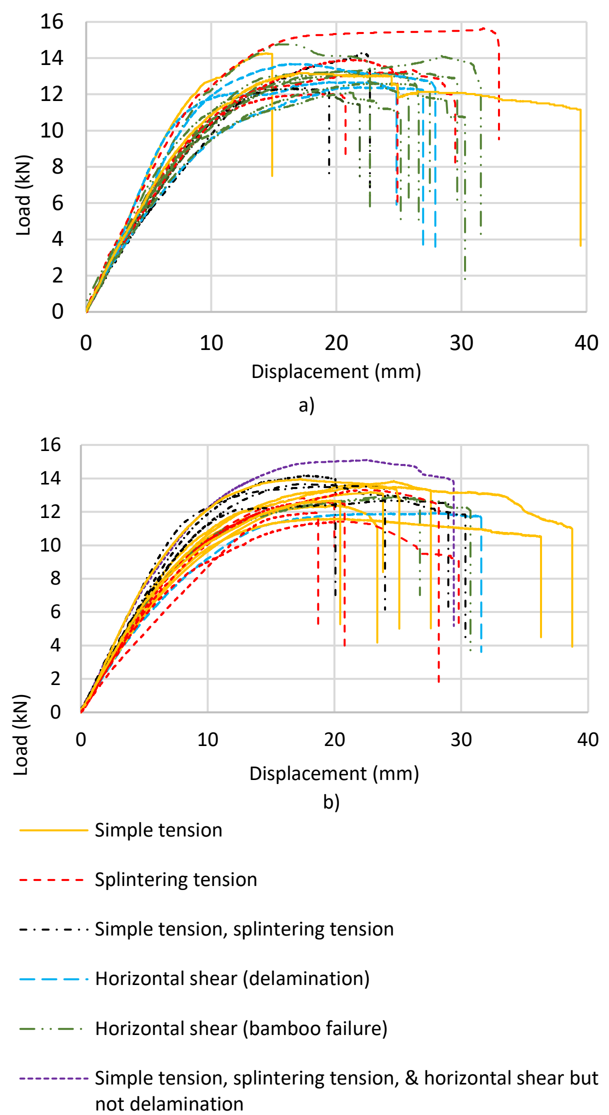


Figure 15. Load-deflection curve in every failure mode of the: a) treated samples and b) untreated samples

Table 4. Failure Mode and Bending Properties of the Treated Sample

Failure Mode	Sample code	Maximum Load, P_{max} (N)	Deflection at P_{max}, ΔP_{max} (mm)	Max deflection, Δ_{max} (mm)	*MOE* (MPa)	*MOR* (MPa)	Adhesive bonding strength*,(MPa)	Ductility index, K&C	Ductility index, Y&K
Mode 1	1L	14,260	21.86	22.68	16,815	116	6.62	3.26	3.14
	3L	12,363	17.33	19.41	16,469	101	7.62	4.13	3.66
	Average	**13,312**	**19.59**	**21.04**	**16,642**	**109**	**7.12**	**3.70**	**3.40**
Mode 2	16L	14,260	14.46	14.86	20,026	117	7.17	3.24	2.70
	20L	13,168	17.79	39.51	19,260	108	8.29	7.84	6.15
	Average	**13,714**	**16.13**	**27.19**	**19,643**	**113**	**7.73**	**5.54**	**4.42**
Mode 3	5L	12,017	19.83	20.73	17,726	99	10.21	4.41	3.78
	7L	15,640	31.78	32.99	23,047	129	7.98	6.27	4.82
	8L	13,340	26.13	29.49	19,544	110	7.62	5.78	4.89
	10L	13,915	21.15	24.88	18,000	113	7.91	4.17	3.23
	Average	**13,728**	**24.72**	**27.02**	**19,579**	**113**	**8.43**	**5.16**	**4.18**
Mode 4	2L	12,334	16.34	21.86	17,199	101	7.16	4.13	3.36
	4L	13,182	24.88	29.65	19,210	107	8.34	6.38	4.88
	6L	13,283	21.70	26.58	18,134	110	8.24	4.81	4.04
	12L	14,778	15.40	22.68	22,257	121	7.16	4.23	1.62
	13L	13,110	21.08	25.78	20,131	109	6.03	4.93	4.11
	14L	14,116	28.41	31.54	17,520	118	5.05	5.68	4.97
	15L	12,621	22.88	30.28	16,785	104	7.02	5.33	4.38
	17L	13,283	20.44	27.46	17,911	111	8.04	5.07	3.99
	19L	12,104	21.04	25.14	21,134	99	6.20	5.30	3.64
	Average	**13,201**	**21.35**	**26.77**	**18,920**	**109**	**7.03**	**5.10**	**3.89**
Mode 5	9L	12,679	19.48	24.80	19,722	104	5.46	6.09	4.16
	11L	12,393	21.40	26.93	17,605	103	5.86	4.80	3.54
	18L	13,685	16.28	27.90	18,310	113	7.65	5.37	2.70
	Average	**12,919**	**19.05**	**26.54**	**18,546**	**107**	**6.33**	**5.42**	**3.46**

* adhesive bonding strength resulted from adhesive bending test following ASTM D905

Table 5. Failure Mode and Bending Properties of the Untreated Sample

Failure Mode	Specimen code	Maximum Load, P_{max} (N)	Deflection at P_{max}, ΔP_{max} (mm)	Max deflection, Δ_{max} (mm)	*MOE* (MPa)	*MOR* (MPa)	Adhesive bonding strength*, (MPa)	Ductility index, K&C	Ductility index, Y&K
Mode 1	4L	14,174	17.59	20.08	18,640	118	7.95	3.91	2.62
	6L	13,512	18.60	35.20	21,874	115	8.24	8.12	5.98
	10L	13,685	17.24	23.99	18,066	116	8.69	4.74	3.79
	12L	12,679	23.78	30.33	18,637	107	8.24	6.40	5.91
	Average	**13,513**	**19.30**	**27.40**	**19,304**	**114**	**8.28**	**5.79**	**4.57**
Mode 2	1L	12,391	19.74	23.38	18,517	102	6.14	4.90	3.93
	2L	13,829	25.13	27.60	17,945	116	7.28	4.90	3.73
	5L	13,570	22.76	38.75	18,434	114	6.93	7.62	6.01
	7L	11,615	18.71	36.29	16,480	97	7.36	7.44	5.95
	8L	13,196	22.86	23.83	16,484	111	8.78	4.09	3.49
	16L	13,973	17.31	25.11	20,352	117	8.12	5.60	5.22
	19L	12,679	19.38	20.45	18,939	107	6.38	4.24	5.59
	Average	**13,036**	**20.84**	**27.91**	**18,164**	**109**	**7.29**	**5.54**	**4.85**
Mode 3	9L	12,823	17.59	19.99	20,115	107	8.33	3.98	3.31
	13L	13,311	26.54	28.23	16,710	110	8.16	5.01	4.24
	14L	11,414	20.08	29.80	16,619	95	6.29	6.03	4.86
	18L	12,579	18.46	20.80	18,095	106	9.08	4.07	3.21
	20L	11,960	18.45	18.71	14,202	100	7.85	2.88	7.19
	Average	**12,417**	**20.22**	**23.51**	**17,148**	**104**	**7.94**	**4.39**	**4.56**
Mode 4	3L	12,966	24.09	26.74	17,496	110	6.00	5.12	4.35
	11L	12,851	24.13	30.73	18,737	106	7.52	6.14	5.02
	Average	**12,909**	**24.11**	**28.73**	**18,117**	**108**	**6.76**	**5.63**	**4.68**
Mode 5	17L	11,932	27.70	31.58	16,145	100	7.46	5.79	5.94
	Average	**11,932**	**27.70**	**31.58**	**16,145**	**100**	**7.46**	**5.79**	**5.94**
Mode 6	15L	15,123	22.55	33.90	21,487	126	8.51	6.66	5.62
	Average	**15,123**	**22.55**	**33.90**	**21,487**	**126**	**8.51**	**6.66**	**5.62**

* adhesive bonding strength resulted from adhesive bending test following ASTM D905

Table 6. *MOE* and *MOR* of LBL Beam

Parameter	Treatment	*N*	Average (MPa)	COV (%)	F_{table}	F_{calc}	$Prob$
MOE	Treated	20	18,840	9.65	4.10	1.22	0.28
	Untreated	20	18,199	10.19			
MOR	Treated	20	110	7.15	4.10	0.07	0.79
	Untreated	20	109	7.32			

not affect the ductility index and it is interesting that specimens that fail due to horizontal shear also show good ductility behaviour. It is reasonable because the specimens achieve P_{max} before the horizontal shear failure occurs.

In the case of the Karacabeyli & Ceccoti (1996) method, the ANOVA result indicates that *deltamethrin* preservative treatment will not affect the ductility index of the LBL beam. In contrast, the ductility index obtained from Yasamura & Kawai (1997) method was affected by this preservative treatment. The different steps in determining P_y may cause this different result. Considering the position of P_y, the Yasamura and Kawai (1997) methods seem to be more accurate to predict P_y because it lay closer to the transition area between elastic-linear to the plastic zone. The ductility index ratio of the treated to untreated samples determined from this method is 0.81.

Modulus of elasticity (MOE) and modulus of rupture (MOR)

Table 4 and Table 5 depict inconsistent pattern neither between bending failure mode and *MOR* nor between bending failure mode and *MOE*. The highest average *MOE* of the treated and untreated specimen was achieved by the specimen failed in mode 2 (19,643 MPa) and mode 6 (21,487 MPa), respectively. Furthermore, the lowest average *MOE* occurred in the specimen the failed in mode 1 (16,642 MPa) for the treated specimen and mode 5 (16,145 MPa) for the untreated specimen. Moreover, the highest average *MOR* of the treated and untreated specimens was found at the specimen that failed in mode 3 (113 MPa) and mode 6 (126 MPa), respectively. The average *MOR* from mode 3 was only 0.3 MPa higher than that of failure mode 2 in the treated specimen. The lowest average *MOR* occurred in failure mode 5 either for the treated or untreated specimen. The lowest average *MOR* of the treated and untreated specimens was 107 MPa and 100 MPa, respectively. .It shows that there is no correlation neither between bending failure mode and *MOR* nor between bending failure mode and *MOE*.

Table 4 and Table 5 indicate that the adhesive bonding strength is greater than the shear strength of the bamboo split. It can be seen that an LBL beam with lower adhesive bonding strength does not necessarily have the lower average value of *MOR*. In other words, the failure depends on the mechanical properties of bamboo split composed LBL.

Table 6 shows that the average *MOE* for the treated and untreated LBL specimens are 18,840 MPa and 18,199 MPa, respectively. The average *MOR* for treated and untreated LBL specimens are 110 MPa and 109 MPa, respectively. It shows that *MOE* and *MOR* of treated and untreated specimen are not significantly different. The ANOVA result with a 95% significant level supported this statement. In other words, the use of 0.01% *deltamethrin* for bamboo preservation in LBL industries does not affect the *MOE* and *MOR* of the LBL beam.

4.0 CONCLUSION

The research results show that the adhesive bonding strength of LBL beam preserved by using 0.01% deltamethrin was higher than the bamboo. It was observed from a rougher surface and grooves of bamboo fiber found in the failure surface plane of adhesive bonding specimen. As a result, the type of bending failure mode does not correlate with the maximum load and deflection. It also causes that the type of bending failure mode does not affect the ductility index.

The research results depict that the preservative treatment using 0.01% deltamethrin will not affect the shear and bending performance of the LBL beam. The average adhesive bonding strength of the treated specimen was 7.28 MPa (ASTM D905) and 7.03 MPa (MD Block), while the average adhesive bonding strength of the untreated specimen reached 7.67 MPa (ASTM D905) and 7.41 MPa (MD Block). Preservative treatment causes reduction of adhesive bonding strength by 5%. The average MOE of the treated and untreated specimens was 18,840 MPa and 18,199 MPa, respectively. The average MOR reaches 110 MPa for treated specimens and 109 MPa for untreated specimens. The load-deflection curves of both treated and untreated specimens for all failure modes show a good ductility property expressed by the ductility index value. The average ductility index of untreated and treated specimens is 4.8 and 3.9, respectively.

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