Experimental Studies on the Mechanical Property of Laminated Bamboo in Thailand

S. Talabgaew, and V. Laemlaksakul

***Abstract*—**A new generation product made from bamboo strips, known as laminated bamboo, has gained importance. The objective of this research was to experiment the effect of three factors on the mechanical property of laminated bamboo. The interested factors for experimental design were (A) four bamboo species, namely *Bambusa blumeana* Schultes (Pai See Suk), *Dendrocalamus asper* Backer (Pai Tong), *Dendrocalamus hamiltonii* Nees (Pai Hok) and *Dendrocalamus sericeus* Munro (Pai Sang Mon), (B) two types of glue adhesive, polyvinyl acetate emulsion (PVAC) fortified with urea-formaldehyde (UF) and urea-formaldehyde (UF) to make parallel-oriented bamboo strips laminates and (C) glue weight per strip area, 150 g/m^2 and 190 g/m^2. Experimental results showed that *Dendrocalamus asper* Backer (Pai Tong) and *Dendrocalamus sericeus* Munro (Pai Sang Mon) were best used for manufacturing due to their highest MOR and MOE. The amount of glue weight 150 g/m^2 yielded higher MOR and MOE than the amount of glue weight 190 g/m^2. At the conclusion, the laminated bamboo manufacturers can benefit from this research in order to select right materials according to strength, cost and accessibility.

***Keywords*—**Laminated Bamboo, Mechanical Property, 3-Way ANOVA.

I. Introduction

IN the past period of composite-materials development, only mechanical and functional performances were taken into account in the design and processing. In recent years, the realization of environmental crisis has dramatically changed the priorities for research and development of composite materials. Now it is time for us to think not only of better performance, but also of how materials and related technologies can become less hazardous to the environment.

Among biological structures, the natural fibers are very interesting for engineering applications due to their low cost and convenient availability. They grow abundantly in tropical and subtropical regions of the world, and they can be usefully employed as construction materials [1, 2].

Most work in the literature that characterizes bamboo is experimental, dedicated to estimating strength and stiffness properties [3, 4]. In these studies, a new ecomaterial, laminate bamboo was developed. Various mechanical properties, including tensile, compressive, flexural strength and shear strength, were measured and compared with those of laminate bamboo. Furthermore, the hygroscopic properties of this new material were also evaluated. Finally, the recycling ability of this material was studied and discussed. All four species hold great potential for value-added utilization and can provide a less expensive and high quality alternative to wood for furniture industrial applications.

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Sompoap Talabgaew is an Assistant Professor in the Teacher Training in Mechanical Engineering Department, King Mongkut’s Institute of Technology North Bangkok, Bangkok, Thailand (e-mail: sptg@kmitnb.ac.th).

Vanchai Laemlaksakul is an Associate Professor in the Industrial Engineering Technology Department, King Mongkut’s Institute of Technology North Bangkok, Bangkok, Thailand (phone: 662-913-2500; fax: 662-587-4356; e-mail: vcl@kmitnb.ac.th).

II. Methodology

A. Bamboo and Preparation of Material

The bamboo used in the present work were Bambusa *blumeana* Schultes (Pai See Suk), *Dendrocalamus asper* Backer (Pai Tong), *Dendrocalamus hamiltonii* Nees (Pai Hok) and *Dendrocalamus sericeus* Munro (Pai Sang Mon) purchased in the Thailand. Bamboos were cut at least one meter above the ground to remove hard solid stem. The first few meters at the bottom of the culms were in general stronger than that at the top. A selected bamboo culms has approximate 120 mm outer diameter and wall thickness 12 mm. Round bamboos were spited with parallel grain into strips. Bamboo strips were dried to low moisture content (12%) as part of the manufacturing process. The detailed were reported previously [5].

Two types of adhesives, namely (1) polyvinyl acetate emulsion (PVAC) fortified with urea-formaldehyde (UF), (2) Urea-Formaldehyde (UF) adhesives were used in the experiments. The adhesives were applied to one side of bamboo strip at 150 g/m^2 and 190 g/m^2. A hydraulic hot press, generally used for making plywood, provided temperature at 150 C, pressure perpendicular to glue-lines at 50 kg/cm^2 and pressing time at 20 minutes. The surfaces of all laminate bamboo were roughened by sandpaper.

B. 3-Way ANOVA

This research focused on the experimental study of three factors as (1) four bamboos species, (2) two glue-weights, and (3) two glue-types as shown in Table I. The laminated bamboos were experimented under these factors to find mechanical properties; Modulus of Resistance (MOR) and Modulus of Elastic (MOE). Each experiment ran 5 replicates so that the total experiments for MOR and MOE testing were 80 runs as shown in Table II respectively. An analysis for this research used three-way analysis of variance (3-Way ANOVA), instead two-level factorial design [6, 7] because factor A (bamboo species) has 4 levels as explained in Table I.

3-Way Analysis of variance (3-Way ANOVA) is similar to Multiple-Regression in that it is used to investigate and model the relationship between a response variable and three independent variables. However, 3-way analysis of variance differs from regression in two ways: the independent variables are qualitative (categorical) or quantitative variable, and no assumption is made about the nature of the relationship that is, the model does not include coefficients for variables. The hypothesis of three factors is for testing the equality of more than two population means, versus them not all being equal [8].

$$H_0 : \mu_1 = \mu_2 = ... = \mu_k$$
$$H_1 : \mu_i \neq \mu_j \text{ for at least one pair (i, j)} \quad (1)$$

C. Testing of Laminated Bamboo

Static bending was considered as one of the important mechanical properties of wood products [9] because it represents the durability and strength especially the new generation furniture design made by laminated bamboo. Static bending properties were tested according to British Standards for Testing Small Clear Specimens of Timber (BS373:1957) using Universal Testing Machine, Testometric FS-300 kN MICO 500.

The dimensions of the central loading specimen are 20 mm width (w) x 20 mm depth (d) x 300 mm length (l) and the distance between the points of support of the test piece (L) is 280 mm. Standard load heads were controlled at the constant speed of 0.26 in/min as shown in Fig. 1.

III. Results

A. MOR Results

The 3-way ANOVA was used to analyzed the experiment and the significant level was set at 0.05 (α = 0.05). Results from MINITAB are shown in Table III.

From Table III, the main factors that strongly affect MOR are bamboo (A) and glue weight (B) at significant level of 0.05 because their p-value is less than 0.05. Glue Adhesive (C) is not significant to MOR because its p-value is larger than p-value [8]. All interactions have no effect on MOR because their p-value is more than 0.05 so they can be ignored for this research.

TABLE I
Factors and Treatments

Factors		Treatment
(A) = Bamboo	1	*Dendrocalamus asper* Backer *(Pai Tong)*
	2	*Bambusa blumeana* Schultes *(Pai See Suk)*
	3	*Dendrocalamus sericeus* Munro *(Pai Sang Mon)*
	4	*Dendrocalamus hamiltonii* Nees *(Pai Hok)*
(B) = Glue Weight	1	150 g/m^2
	2	190 g/m^2.
(C) = Glue Adhesive	1	Polyvinyl acetate + Urea formaldehyde *(PVAC + UF)*
	2	Urea-formaldehyde*(UF)*

TABLE II
The Design of Experiment for MOR and MOE

Bamboo (A)	Glue Weight (g/m^2) (B)	Glue Types (C)	
		PVAC + UF	UF
Pai Tong	150	5 Replicates	5 Replicates
	190	5 Replicates	5 Replicates
Pai See Suk	150	5 Replicates	5 Replicates
	190	5 Replicates	5 Replicates
Pai Sang Mon	150	5 Replicates	5 Replicates
	190	5 Replicates	5 Replicates
Pai Hok	150	5 Replicates	5 Replicates
	190	5 Replicates	5 Replicates

Fig. 1 Static Bending Testing

TABLE III
MOR RESULTS

General Linear Model: MOR versus Bamboo (A), Glue Weight (B), Glue Adhesive (C)

Factor	Type	Levels	Values
Bamboo (A)	fixed	4	1, 2, 3, 4
Glue Weight (B)	fixed	2	1, 2
Glue Adhesive (C)	fixed	2	1, 2

Analysis of Variance for MOR

Source	DF	SS	Adj MS	F	P
Bamboo (A)	3	23085.3	7695.1	9.86	0.000*
Glue Weight (B)	1	3586.5	3586.5	4.59	0.036*
Glue Adhesive (C)	1	2804.1	2804.1	3.59	0.062
(A)*(B)	3	5620.3	1873.4	2.40	0.076
(A)*(C)	3	377.7	125.9	0.16	0.922
(B)*(C)	1	943.2	943.2	1.21	0.276
Error	67	52299.5	780.6		
Total	79	88716.6			

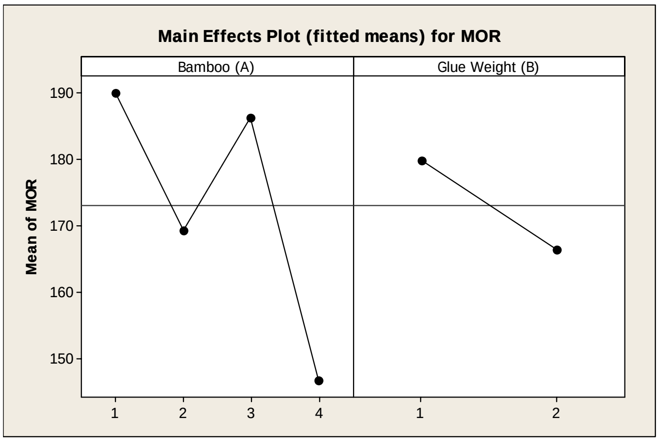

Fig. 2 Main effects plot for bamboo (A) and glue weight (B) affecting to MOR

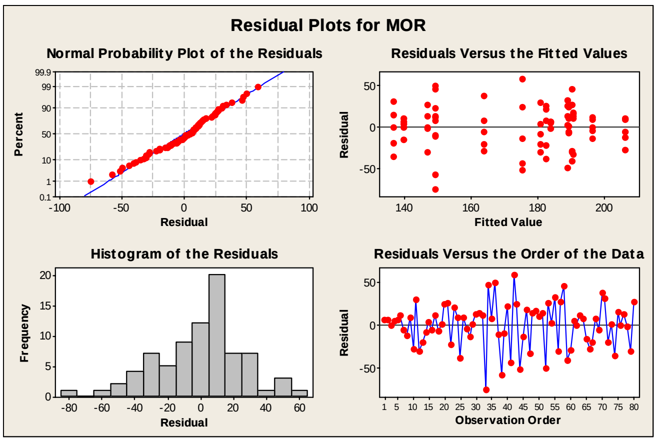

Fig. 3 Residual plots for MOR

TABLE IV
MOE RESULTS

General Linear Model: MOE versus Bamboo (A), Glue Weight (B), Glue Type (C)

Factor	Type	Levels	Values
Bamboo (A)	fixed	4	1, 2, 3, 4
Glue Weight (B)	fixed	2	1, 2
Glue Type (C)	fixed	2	1, 2

Analysis of Variance for MOE

Source	DF	Seq SS	Adj MS	F	P
Bamboo (A)*	3	104771687	34923896	15.37	0.000*
Glue Weight (B)*	1	18760814	18760814	8.26	0.005*
Glue Type (C)	1	5786190	5786190	2.55	0.115
(A)*(B)*	3	18861259	6287086	2.77	0.048*
(A)*(C)*	3	21968288	7322763	3.22	0.028*
(B)*(C)	1	4905947	4905947	2.16	0.146
Error	67	152198153	2271614		
TOTAL	79	327252338			

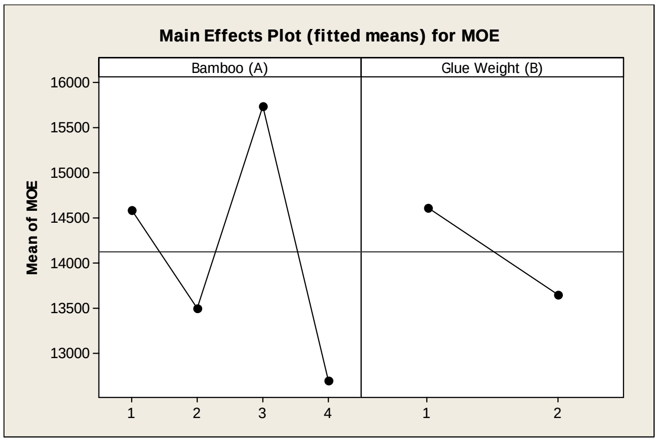

Fig. 4 Main effects plot for bamboo (A) and glue weight (B) affecting to MOE

Normally, the MOR of laminated bamboo should be as much as possible. From Fig. 2, Bamboo factor (A), Pai Tong (labeled as 1) has the highest MOR and Pai Sang Mon (labeled as 3) has the second highest MOR but, on the other hand, Pai Hok (labeled as 4) has the lowest MOR. It can be said that Pai Tong and Pai Sang Mon can be substituted each other because there are not much different MOR. Glue weight (B), at the amount 150 g/m^2 (labeled as 1), yields more MOR than at the amount 190 g/m^2 (labeled as 2).

Fig. 3 shows the residual plot of MOR and all residual plots are normally distributed and randomly. This can be concluded that the experimental design for MOR was fairly acceptable.

B. MOE Results

Results of MOE analysis were as same as MOR analysis. The results from MINITAB are shown in Table IV.

The main factors that strongly affect MOE are still bamboo species (A) and glue weight (B) at significant level of 0.05 because their p-value is less than 0.05. Glue Again, glue adhesive (C) is not significant to MOE because its p-value is larger than p-value [8]. However, there are slightly different from MOR results because MOE results yield interaction effects that are interactions AB and AC because their p-value is less than 0.05 as shown in Table IV. Although interaction AC (Bamboo*Glue Adhesive) is significant, Glue Adhesive (C) is not significant so that its interaction can be ignored as well. This research only considered AB interaction. Similarly, MOE of laminated bamboo should be as much as possible as well. From Fig. 4, bamboo factor (A), Pai Sang Mon (labeled as 3) has the highest MOE and Pai Tong (labeled as 1) has the second highest MOE that are totally opposite from MOR results but, as same as MOR results, Pai Hok (labeled as 4) is still the lowest MOE. It can be concluded that Pai Tong and Pai Sang Mon can be substituted each other because there are not much different MOE. Glue weight (B), at the amount 150 g/m^2 (labeled as 1) yields more MOE than at the amount 190 g/m^2 (labeled as 2).

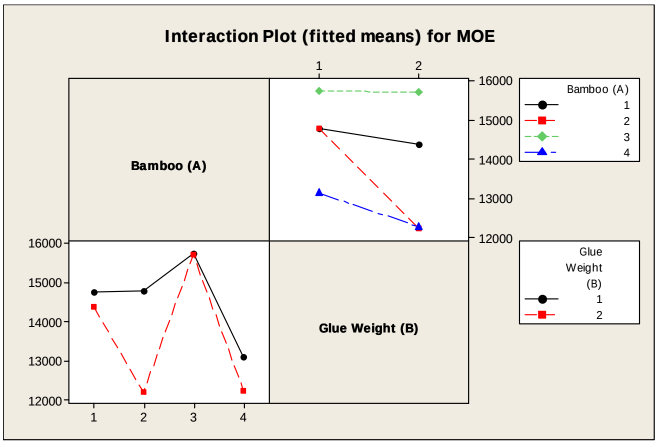

Fig. 5 Interaction plots for bamboo (A) and glue weight (B) affecting to MOE

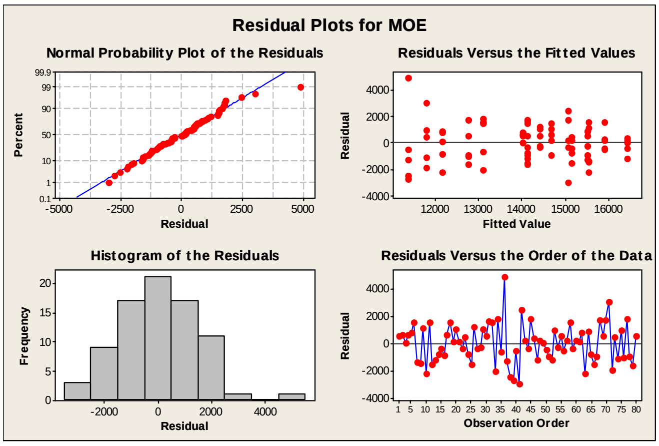

Fig. 6 Residual plots for MOE

Fig. 5 shows the interaction effect AB (bamboo*glue weight). Considering the top right plot, at glue weight 150 g/m^2 level (labeled as1) seems to gain higher MOE than at glue weight 190 g/m^2 (labeled as 2) when it interacts with Pai Sang Mon (dotted line) and Pai Tong (solid line). At the same way, a bottom left plot, the number 1, 2, 3, and 4 on X-axis represents each bamboo species. Pai Sang Mon (labeled as 3) and Pai Tong (labeled as 1) yield higher MOE when they interact with glue weight at the amount 150 g/m^2 (solid line) than at the amount 190 g/m^2 (doted line). These interpretations follow the MINITAB results in Table IV.

Fig. 6 shows the residual plot of MOE and all residual plots are normally distributed and randomly. This can be concluded that the experimental design for MOR was fairly acceptable.

IV. Conclusion

This research was aimed to find the appropriate factors affecting mechanical properties of laminated bamboo (MOR and MOE) by using experimental design. Three-way analysis of variance (3-way ANOVA) is of interest because each factor has different level. Bamboo species (A), Glue weight and Glue type have 4, 2 and 2 levels respectively.

The amount of experiments was 80 runs. The MOR results show that the main factors affecting to MOR of laminated bamboo are only bamboo species (A) and glue weight (B) but glue type (C) is not significantly influenced. There are no any interaction effects affecting to MOR. For bamboo species (A), Pai Tong yields the highest MOR and Pai Sang Mon is the second highest MOR For glue weight (B), the amount of glue weight 150 g/m^2 gives higher MOR than the amount of glue weight 190 g/m^2.

The MOE results are most likely as same as MOR results. Bamboo species (A) and glue weight (B) are still significant to mechanical properties of laminated bamboo. Unlike MOR results, Pai Sang Mon yields the higher MOE than Pai Tong. The amount of glue weight 150 g/m^2 gives higher MOE than the amount of glue weight 190 g/m^2. Furthermore, there is AB interaction effect (bamboo species*glue weight).

The benefits from this research can help the large-scale laminated bamboo production selecting right materials according to strength and cost as follows;

1) Pai Tong or Pai Sang Mon is the best for laminated furniture manufacturing due to its mechanical properties.

2) The MOR and MOE of using glue weight 150 g/m^2 and 190 g/m^2 are not different resulting to cost-effective production.

3) Glue types (PVAC + UF and UF) are not influenced to mechanical and physical properties of laminated bamboo so the manufacturers can use either one of them depending on accessibility, cost, environmental effect, safety etc.

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