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Study of the Appropriate Factors for Laminated Bamboo Bending by Design of Experiments

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***Abstract*—**This research studied the appropriate factors and conditions for laminated bamboo bending by Design of Experiments (DOE). The interested factors affecting the spring back in laminates bamboo were (1) time, (2) thickness, and (3) frequency. This experiment tested the specimen by using high frequency machine and measured its spring back immediately and next 24 hours for comparing the spring back ratio. Results from the experiments showed that significant factors having major influence to bending of laminates bamboo were thickness and frequency. The appropriate conditions of thickness and frequency were 4 mm. and 1.5 respectively.

***Keywords*—**Bamboo, Bending, Spring Back, Design of Experiments (DOE).

I. Introduction

THE greenhouse effect caused by the increasing CO_2 concentration in the atmosphere is predicted to produce drastic changes in the global climate. Forests, especially tropical rain forests, are the most important ecosystems for CO_2 fixation and therefore forests should be well managed. To save the forest, it is not appropriate to use wood as a structural material. For this reason, bamboo has attracted much attention during recent years.

Apart from being one of the fastest growing plants, so that harvest time can be short, bamboo has such attractive features as high specific strength and modulus, low density and, as a natural material, its degradability. Recently, the use of bamboo has been expanded to include its manufacture into various structural composite products [1, 2]. Previous studies showed that Dendrcalamus asper Backer bamboo's favorable mechanical properties make it a premising material for the manufacture of various engineered laminated products, such as laminated bamboo armchair [3].

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This research was to find the appropriate factors and their levels influencing to spring back of laminated bamboo because most dining chairs produced from laminated bamboo are assembled with many bended parts such as armrest and backrest. It can be said that "the less spring back, the better design". In the past, manufacturers used their own experiences or trial and error to find the standard so that it wasted time and cost. In order to enhance the laminated bamboo manufacturing in Thailand, DOE is of interest to solve the problem mentioned [4].

II. Experiments

A. Specimen Preparation

The bamboo wood in this study was brought from Samutsakorn Province with 1.10 meter-long and cut in different sizes that were, 4 x 40 x 800 mm. and 6 x 40 x 800 mm. (thickness x width x length).

B. Screening Experiment Design

This study focused on the spring back of the armrest of armchair by applying 2^k Factorial design for experiment. Each factor was considered as 2 levels. As mentioned earlier, the different thickness was taken into considered of this study because the thickness directly involves either the design of manufacturing process or material cost reduction. The low and high levels of the thickness of laminated bamboo were 4 mm. and 6 mm. respectively. When you submit your final version, after your paper has been accepted, prepare it in two-column format, including figures and tables.

In order to conduct the experiment, the levels of frequency and time must be known. This experiment tested the laminated bamboo at different level of frequency (1.5, 2.0, 2.5) and time (2, 3 minutes). From Table I, the laminated bamboo failed after setting the frequency at 2.5, so that the interested level of frequency for this experiment were only 1.5 and 2.0. The levels of time were 2 and 3 minutes as shown in Table I. The reason for finding 2 different levels for experimenting is followed by the 2^k Factorial Design that requires each factor has to have 2 levels.

The laminated bamboo specimens were randomly selected to measure the relative humidity. There were 6 specimens with 4 millimeter-thickness and 4 specimens with 6 millimeter-thickness. All specimens were glued with urea-formaldehyde [5, 6] and taken them for testing by the high frequency machine and each experiment had 3 replications as shown in Table II. After testing, each laminated bamboo specimen was measured its spring back immediately and left 24 hours for measuring its spring back again.

III. Results

The factors in this experiment were (1) time, (2) thickness and (3) frequency and each factor has 2 levels as shown in Table III.

From Table IV, the factors that strongly affect spring back are thickness and frequency at significant level of 0.05 because their p-value is less than 0.05. A time factor is not significant to spring back because its p-value is larger than p-value [4].

From Fig. 1, the thickness (or appeared as B) and frequency (C) are significant factors affecting to spring back but the time factor is not significant to spring back. The interaction AB (time*thickness) and AC (time*frequency) can be ignored because the main effect A (time) is not significant to spring back [4]. Fig. 2 shows the main effects plot for the influenced factors (thickness and frequency).

TABLE I
Summary of Testing Frequency for the Experiment

Thickness	Anode Voltage	Filament Voltage	Frequency	Time	Results
4	3	3	2.5	3	Failure
4	2	3	2.5	3	Failure
4	2	3	2	2	Uncompleted glue adhesion
4	2	3	2	3	Survive
6	2	3	2	2	Survive
6	2	3	2	3	Survive
4	2	3	1.5	2	Survive
4	2	3	1.5	3	Survive
6	2	3	1.5	2	Survive
6	2	3	1.5	3	Survive
4	1	2	2	3	Survive
					Uncompleted glue adhesion

TABLE II
The Design Matrix for 2^3 Factorial Design

No.	Thickness	Frequency	Time	Spring back
1	-	-	-	Replications 1,2,3
2	+	-	-	Replications 1,2,3
3	-	+	-	Replications 1,2,3
4	+	+	-	Replications 1,2,3
5	-	-	+	Replications 1,2,3
6	+	-	+	Replications 1,2,3
7	-	+	+	Replications 1,2,3
8	+	+	+	Replications 1,2,3

TABLE III
The Low and High Levels for Each Factor

Factors	Low Level (-)	High Level (+)
Time	2 min.	3 min.
Thickness	4 mm.	6 mm.
Frequency	1.5	2.0

TABLE IV
Estimated Effects and Coefficients for Spring Back (Immediate Measure)

Term	Effect	Coef.	T	P
Constant		7.626	6.71	0.000
Time	-4.159	-2.08	-1.83	0.085
Thickness	6.752	3.376	2.97	0.009
Frequency	5.833	2.916	2.57	0.020
Time*Thickness	-5.313	-2.656	-2.34	0.032
Time*Frequency	-6219	-3.11	-2.74	0.014
Thickness*Frequency	6.226	3.113	2.74	0.014

S = 5.56681 R-Sq = 69.76% R-Sq(adj) = 59.09%

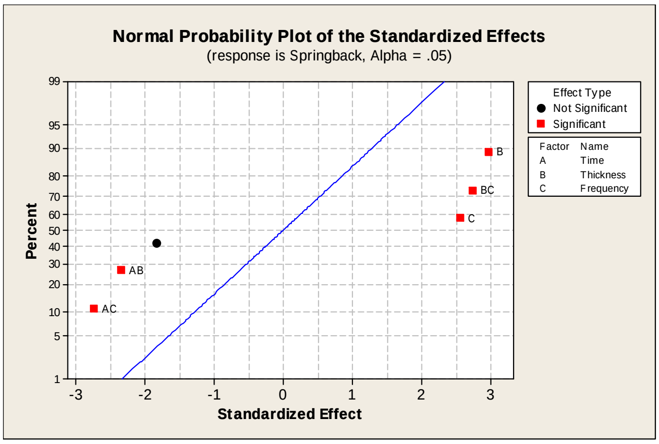

Fig. 1 Factors affecting spring back after immediate measuring

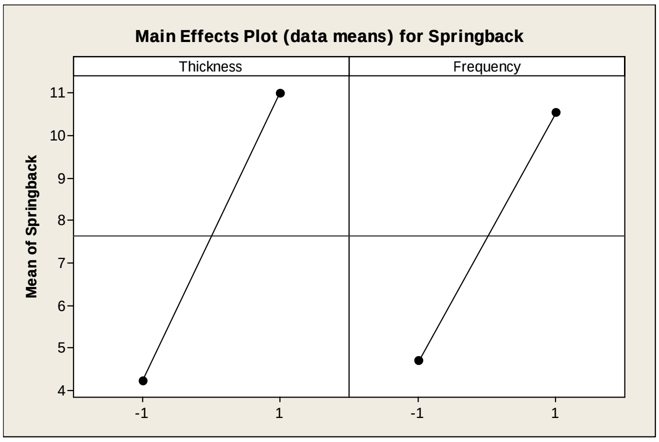

Fig. 2 Main effects plot for thickness and frequency after immediate measuring

Normally, the spring back should be as less as possible. The appropriate conditions of main effects (thickness and frequency) are set at the low level (-1), shown in Fig. 2, because at the low level of both factors yields the less spring back than the high level (+1). As followed in Table IIı, the low level of thickness and frequency is 4 mm. and 1.5 respectively.

From Fig. 3, a contour plot shows the interaction of thickness and frequency affecting to spring back. If the spring back is required less than 5%, the appropriate conditions for both factors should be set at low level (-1). These conditions of interaction are according to the level of main effect those are 4 mm. thickness and frequency 1.5.

From Table V, the result, from measuring spring back in next 24 hours, closes to the result in Table IV. The significant factors are thickness and frequency at significant level of 0.05 because their p-value is less than 0.05. Time is still not significant to spring back because its p-value is larger than p-value so that, as mentioned earlier, interaction AB (time*thickness) and AC (time*frequency) can be ignored. The significant main effect and interaction are plotted in a Normal Probability Plot (NOPP) in Fig. 4.

Again, the appropriate level of thickness and frequency after measuring in next 24 hours are at the low level according to immediate measuring. The appropriate conditions of main effects (thickness and frequency) are set at the low level (-1), shown in Fig. 5.

From Fig. 6, this contour plot looks similar to the Fig. 3. It shows the interaction of thickness and frequency affecting to the different percent of spring back. If the spring back is required less than 5%, the appropriate conditions for both factors should be set at low level (-1). These conditions of interaction are according to the level of main effect which is thickness 4 mm. and frequency 1.5.

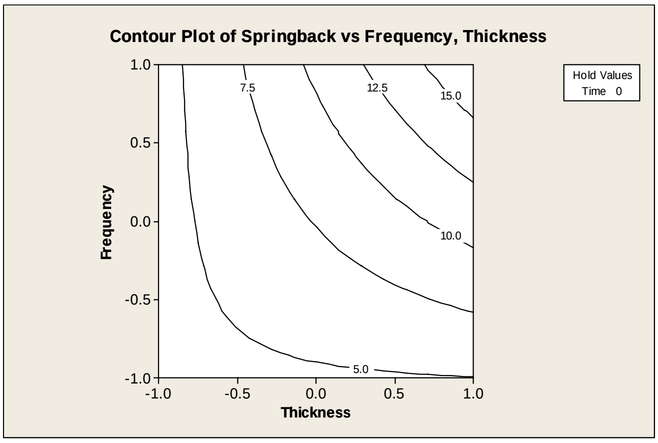

Fig. 3 Contour plot for interaction thickness and frequency after immediate measuring

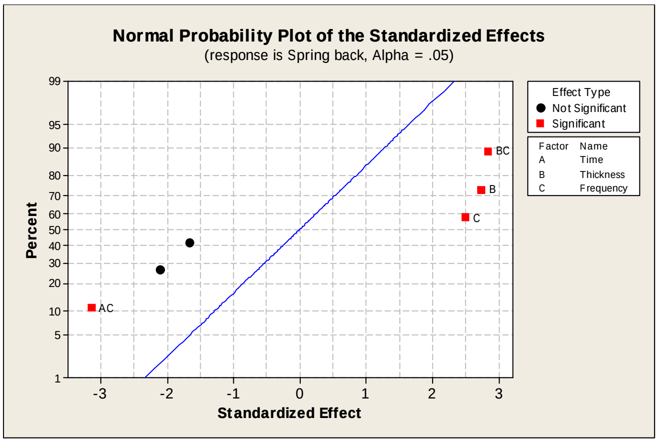

Fig. 4 Factors affecting spring back after measuring in next 24 hours

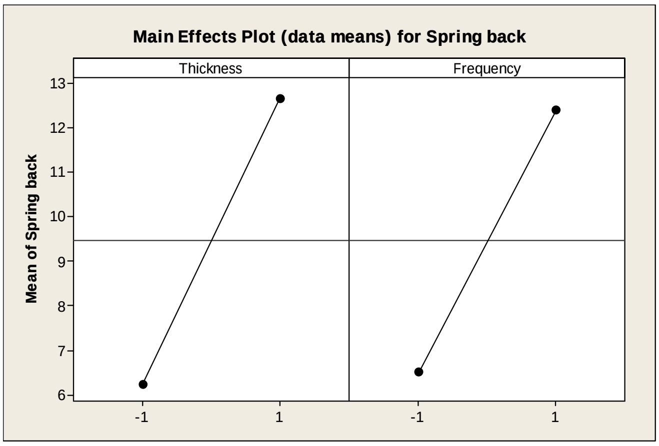

Fig. 5 Main effects plot for thickness and frequency after measuring in next 24 hours

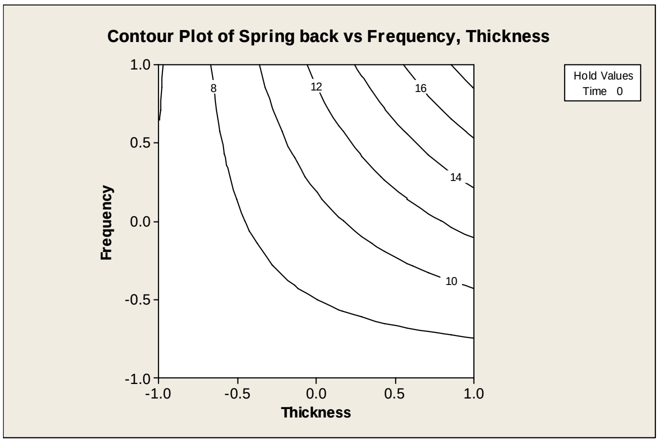

Fig. 6 Contour plot for interaction thickness and frequency after measuring in next 24 hours

TABLE V
ESTIMATED EFFECTS AND COEFFICIENTS FOR SPRING BACK (24 HOURS)

Term	Effect	Coef.	T	P
Constant		9.464	8.09	0.000
Time	3.883	1.942	1.66	0.115
Thickness	-6.422	-3.211	-2.74	0.014
Frequency	-5.870	-2.935	-2.51	0.023
Time*Thickness	-4.927	-2463	-2.11	0.050
Time*Frequency	-7.332	-3.666	-3.13	0.006
Thickness*Frequency	6.657	-3.328	2.85	0.011

S = 5.73065   R-Sq = 69.61%   R-Sq(adj) = 58.88%

IV. CONCLUSION

This research was aimed to find the appropriate factors affecting bamboo laminated bending by using Factorial Design. A 2k Factorial Design requires that each factor has to have 2 levels: high level (+) and low level (-). The interested factors for this research were as following table VI.

TABLE VI
THE EXPERIMENTED FACTORS

Factors	Low level (-)	High level (+)
Bending Time	2 minutes	3 minutes
Bamboo Thickness	4 mm.	6 mm.
Frequency	1.5	2.0

The amount of experiments was $2^3 = 8$ experiments with 3 replications for each so the total experiments were 24 experiments. Each specimen was glued by Urea-Formaldehyde for laminating and then it was fit into a bending machine with 250 mm-radius mould included.

After finishing the experiment, there were 2 alternatives as follows:

1) The spring back was immediately calculated and

2) The spring back was later calculated in next 24 hours.

The results from Minitab version 14 showed that the influenced factors affecting to spring back were only thickness and frequency but Time was not significantly influenced. As the minimized spring back was mainly an objective, the further analysis found that the appropriate level for Thickness was 4 mm. and Frequency was 1.5.

The benefits from this research can be of interest to designing or manufacturing the armrest of dining chair or related furniture [4].

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