



Optimization of Treatment Parameters to Enhance Bending Strength of Bamboo

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Abstract. Bamboos are evergreen perennial flowering plants in the subfamily Bambusoideae of the grass family poaceae. The word “bamboo” comes from kannada term bamboo, which introduced to English through Indonesia and Malay. Bamboo is the most amply found with remarkable mechanical property. The investigation essence on optimization of treatment parameters to enhancement bending strength of bamboo. Treatment conditions taken at: 50 °C, 100 °C and 150 °C with palm oil for 30 min, 50 °C, 100 °C and 150 °C with boil water for 30 min. Soaking with water for 30 min, 1 h and 1.5 h, baking with for 30 min, 1 h and 1.5 h, baking for 20 min, 40 min and 60 min at 150 °C and exposing to smoking for 30 min, 60 min and 90 min; the optimum result obtained on specimens treated in water soaking for 90 min; boiled in oil with 150 °C for 30 min boiling in water for 30 min at 150 °C; smoking for 90 min and baking at 150 °C for 60 min results the best performance on bamboo sample ultimately. Optimization confirmed with predicted bending strength and achieved 73.11% of enhancement.

Keywords: Bambusoideae · Bamboo · Optimal · Bending strength · Taguchi

1 Introduction

Bamboo plays a major role in the economy of rural people and industry [1–3]. They are widely used for house for house constructions, bridges, fencing basketry, furniture, mats, agriculture tools, handles for tools, musical instruments, fishing rods, scaffolding, weaving materials, pole and post, paper and pulp making, food for humans and livestock [4–7]. Bamboo can even use for medical areas as a benefit inspired by the bending and energy absorption characteristics [8].

Natural available plant bamboo has high strength, variety of purposes [2, 9]. Comparing between steel and bamboo with respect to its mechanical property specially, bending, is much lower [10]. Bamboo can be preserved either by using chemicals (chemical treatment) or without using chemicals (traditional treatment) to prolong their durability [11].

Investigation of mechanical behavior of bamboo can be done with FEM, Taguchi design of experiment and other methods, which can comfort to the design data and circumstance [12].

Nevertheless, based on specific specie of this natural plant (bamboo) sufficient available data is very rare [13] when compared to other known species or known structural materials. Henceforth, this study paves away to further studies.

1.1 Objective

General objective of the study is optimizing the treatment parameters to enhance bending strength and examine extent in which process parameters improve mechanical properties of dendrocalamus membranous munro bamboo.

2 Methodology, Materials and Methods

2.1 Methodology

This study takes an experimental investigation of process parameters of treating bamboo for enhancing its mechanical properties.

2.2 Materials

Dendrocalumose membranous munero bamboo is one of the most extracted bamboo species in Awi zone was used for the purposes using traditional or non-chemical preservation. Methods like water soaking, heating and cooling in oil, baking, heating and cooling in water and smoking are the main methods that followed by people to enhance the mechanical properties of harvested bamboos before their multipurpose uses.

First, bamboo specimens with length of 260mm and 4mm in diameter treated to decrease their sensitivity to moisture and improve their durability. Treatment conditions taken at; 50 °C, 100 °C and 150 °C with palm oil for 30 min, 50 °C, 100 °C and 150 °C with boil water for 30 min, soaking with water for 30 min, 1 h and 1.5 h, baking with 20 min, 40 min and 60 min at 150 °C and exposing to smoking for 30 min, 60 min and 90 min.

2.3 Testing Equipment

For this research specimen bending specimen 47DIN5010 bamboos was used [14]. Universal bending testing machine Germany version 50110-1:2013 was used to measure the bending strength of the natural bamboo (Fig. 1).

2.4 Design of Experiment (DOE)

To come up with the required process optimization of point of interest, statistical method is one of the key tools. DOE is one of this kind. DOE is profuse tactics for exploring multi-factor prospect where effect of every process parameters each and combination of interrelation investigated. DOE offers a good understanding in finding of robust system. Taguchi practices for superiority quality to improve products and processes. Analysis



Fig. 1. Universal testing machine

carried out making use of Taguchi’s design of experiment due to its small number of experiments to execute.

Likely fixed and control process parameters sorted out and summarized as shown in Table 1 and 2. Taguchi method mainly uses possible combinations of experimental trial making use of Latin square [8], which has properties of orthogonal array representation. Depending up on number of control factors and its unique properties of L₂₇ (3⁵) orthogonal array is suitable [15].

Table 1. Fixed factors

Fixed factors	Value
Thickness	3.5 mm
Condition	Dry
Length	260 mm

Improving required (point of interest) quality fall in to three categories: larger the better, smaller the better and nominal the best type [16]. Based on quality criteria improvement signal-to-noise quantification shall be evaluated. Henceforth, improving quality endeavored check as determination to make best use of the signal to noise (S/N) ratio.

The aim of this study is to enhance flexural strength of natural bamboo can categorized in maximum-the-better criterion. Consequently, signal-to-noise ratio (η) calculated as:

$$\eta = -\log \left[\sum_{i=1}^r 1/y_i^2 \right] \tag{1}$$

Table 2. Control process parameters

Control factors		Level		
		1	2	3
A	Water soaking, [min]	30	60	90
B	Boiling in oil. [°C]	50	100	150
C	Boiling in water. [°C]	50	100	150
D	Smoking [min]	30	60	90
E	Baking [min]	20	40	60

Where r is trial and y_i observations under different noise situations. A level that make the most of signal-to-noise ratio for factors that will be substantial result. Hence, optimal conditions for flexural strength process easily determined. Value of η_i at is optimal conditions calculated using Eq. (2) [15].

$$\eta_{opt} = m + \sum (m_i - m) \tag{2}$$

Where η_{opt} is S/N ratio at best situations, m is overall average value for trials, and m_i is the η_i under best settings for i th factor. Depending up on how close average of combination of best parameters and expected one, η_{opt} ; in general, within 90%, it can have said to be important factors are not missed, there is no interaction between the factors and design is remains at its robustness.

3 Experimental Setup

The optimum marks obtained on specimens treated in water soaking for 90 min; boiled in oil with 150 °C for 30 min; boiling in water for 30 min at 150° C; smoking for 90 min and baking at 150 °C for 60 min.

An experiment result on parameters optimization for flexural strength has measured five times and intended using Eq. (1) for individual experimental conferring to number of measurements. Besides to this, average of each of control factors signal-to-noise ratio was calculated and summarized in Table 5 (Table 3).

Table 3. Experimental setup according to Taguchi's DOE

Exp.	A.[min]	B.[min]	C.[min]	D.[min]	E.[min]
1	30	50	50	50	50
2	30	50	50	30	40
3	30	50	50	30	60
4	30	100	100	60	20
5	30	100	100	60	40
6	30	100	100	60	60
7	30	150	150	90	20
8	30	150	150	90	40
9	30	150	150	90	60
10	60	50	100	90	20
11	60	50	100	90	40
12	60	50	100	90	60
13	60	100	150	30	20
14	60	100	150	30	40
15	60	100	150	30	60
16	60	150	50	60	20
17	60	150	50	60	40
18	60	150	50	60	60
19	90	50	150	60	40
20	90	50	150	60	40
21	90	50	150	60	60
22	90	100	150	90	20
23	90	100	50	90	40
24	90	100	50	90	60
25	90	150	100	30	20
26	90	150	100	30	40
27	90	150	100	30	60

Samples with different parameters combinations are shown in Fig. 2 below.



Fig. 2. Bamboo samples at different parameters combinations

4 Result and Discussion

4.1 Bending Strength Analysis

Experimental results on parameters optimization in improving bending strength of bamboo measured and summarized as shown in Table 4. Furthermore, response of S/N ratio calculated using Eq. (1) for each trial according to number of measurements recurrence. In addition to this, average of each of control factors S/N ratio was calculated and summarized in Table 5.

Table 4. Experimental results

Exp	A	B	C	D	E	Flexural strength [M pa]	S/N	Mean [M pa]
1	1	1	1	1	1	6.6	16.3909	6.600
2	1	1	1	1	2	9.46	19.5178	9.460
3	1	1	1	1	3	12.782	22.1320	12.782
4	1	2	2	2	1	17.6	21.9103	17.600
5	1	2	2	2	2	27.082	28.6536	27.082
6	1	2	2	2	3	40.48	32.1448	40.480
7	1	3	3	3	1	64.064	36.1323	64.064
8	1	3	3	3	2	66.572	36.4658	66.572
9	1	3	3	3	3	123.772	41.8524	123.772
10	2	1	2	3	1	34.958	30.8709	34.958
11	2	1	2	3	2	37.796	31.5489	37.796
12	2	1	2	3	3	41.866	32.4372	41.866
13	2	2	3	1	1	31.878	30.0978	31.878
14	2	2	3	1	2	37.026	31.3701	37.026
15	2	2	3	1	3	44.704	33.0069	44.704

(continued)

Table 4. (continued)

Exp	A	B	C	D	E	Flexural strength [M pa]	S/N	Mean [M pa]
16	2	3	1	2	1	38.852	31.7883	38.852
17	2	3	1	2	2	40.37	32.1212	40.37
18	2	3	1	2	3	53.328	34.5391	53.328
19	3	1	3	2	2	57.926	35.2575	57.926
20	3	1	3	2	2	63.426	36.0453	63.426
21	3	1	3	2	3	72.05	37.1527	72.05
22	3	2	1	3	1	56.826	35.0909	56.826
23	3	2	1	3	2	61.6	35.7916	61.600
24	3	2	1	3	3	68.299	36.6886	68.299
25	3	3	2	1	1	64.548	36.1977	64.548
26	3	3	2	1	2	67.936	36.6420	67.936
27	3	3	2	1	3	74.558	37.4499	74.558

Table 5. Control variables signal-to-noise ratio

Level	Water soaking	Heating in oil	Boiling in water	Smoking	Baking
1	28.69	29.04	29.34	29.20	30.75
2	31.97	31.97	32.32	32.51	32.02
3	36.26	35.91	35.26	35.21	34.16
Delta	7.57	6.87	5.92	6.01	3.41
Rank	1	2	3	4	5

4.2 Optimum Levels

Optimum process parameters and their levels are determined according to experimental outputs and Table 5 reveals optimum blends of control factors grounded on its uppermost average value of S/N ratio. Hence, the optimum blend and stages are A3B3C3D3E3, short listed and shown in Table 6. Moreover, from the normal probability plot (Fig. 4) it can deduce that the experiment doesn't interact between control parameters.

4.3 Confirmation Experiment

From validate test, it is obvious an enhancement of bending strength from 92.8968Mpa to 127.053Mpa with a minimum error of 2.73%. it shows about 73.11% increment.

$$\text{Total Error} = (\text{error/total}) * 100\%$$

$$\text{Total allowance error} = (0.3158/11.5513) * 100\% = 2.73\%$$

Percentage error (% error) = [(Experimental Value-Theoretical value)/theoretical value] *100 (Fig. 3).

Table 6. Optimum process parameters

Factor		level	value
A	Water soaking, [min]	3	90
B	Heating in oil, [°C]	3	150
C	Boiling in water, [°C]	3	150
D	Smoking, [min]	3	90
E	Baking, [min]	3	60

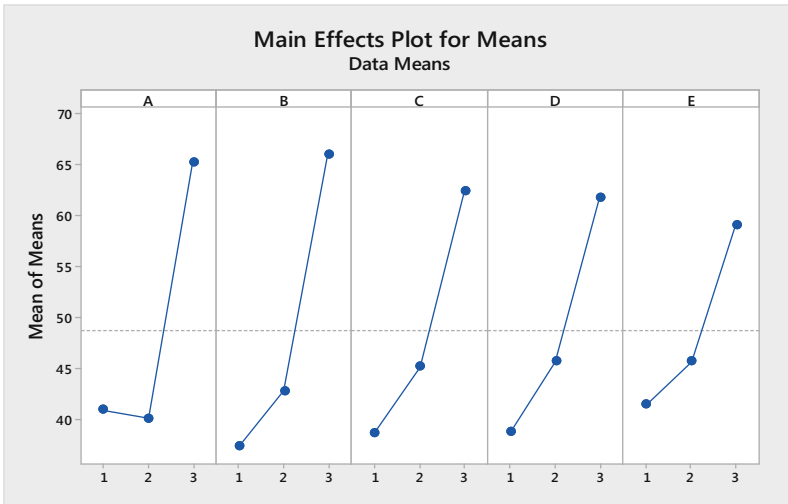


Fig. 3. Plot of S/N ratio

5 Analysis of Variance (ANOVA)

To find among all the process parameters which one is the influential one, statistical approach analysis is carried out. One of the methods is Anova. Anova tests by comparing variance. Hence, in this experimental investigation the main effects, significant factors are identified using F ratio test. Roysl et al. [17] suggest one factor can pool as an error if its influence with respect to sum of square (SS) is less or equal to 10%. It indicates the significance of the individual control factors and their interactions. As shown in Table 5 all parameters have p-values less than 0.1, which means those variables, have higher influence on the bending strength of natural bamboo in high regard (Table 7).

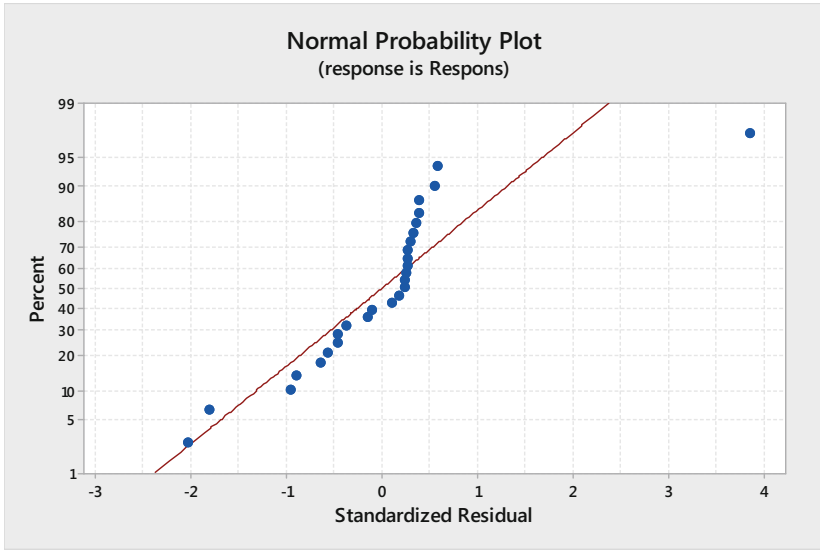


Fig. 4. Normal probability plot

Table 7. Analysis of variance (ANOVA)

Source	DF	Seq SS	Adj SS	Adj MS	F-value	p-value	Contribution	Significance
Water soaking	2	25.351	25.351	12.6755	51.01	0.000	27.22%	significant
Boiling in oil	2	24.096	24.096	12.0482	48.49	0.000	25.87%	significant
Boiling in water	2	16.385	16.385	8.1927	32.97	0.000	17.59%	significant
Smoking	2	16.033	16.033	8.0166	32.26	0.000	17.21%	significant
Baking	2	7.300	7.300	3.6500	14.69	0.000	7.84%	significant
Error	16	3.976	3.967	0.2485			4.27	
Total	26	93.142					100%	

6 Conclusions and Recommendations

6.1 Conclusion

Optimalizations is done for enhancing the bending strength and increased from 92.8668Mpa to 127.053Mpa with a minimum error of 2.7%. The confirmatory test was done by taking the optimal parameters and the result is 108.52Mpa which is between the critical intervals and shows that the improvement of the response variable is accepted and also shows that the method that was used to optimize was valid. The study found that all the factors had significant influence on the response variables.

In this paper, parameters optimization on enhancement of bending strength for natural bamboo has presented. Making use of Taguchi's experimental method L27 orthogonal array employed. Moreover, ANOVA analysis also carried out to determine main factors, which would affect significantly surface roughness improvement. Consequently, 90 min of soaking in water 150 °C of heating in oil, 150 °C of heating in water, 60 min of baking and 60 min of smoking have found to be optimal parameters. It was observed that about 73.11% improvement from 92.8968Mpa to 127.053Mpa has been achieved using the optimal parameters.

6.2 Recommendations

The author recommends further investigation of bamboo mechanical properties based on different fiber thickness and other issues shall addressed to come up with an overall judgment of this abundantly available plant.

The author also advices to other researchers to conduct detail experimental investigation on additional physical and mechanical properties of the composite like: density, shear strength, tensile test and other.

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