Application of Response Surface Methodology models for dimensional stability of hydrothermally treated Semantan bamboo

Zaidon Ashaari, Lee Seng Hua, Juliana Abdul Halip, Syeed SaifulAzry Al Edrus, Lum Wei Chen, Lee Ching Hao

Abstract*: *Semantan bamboo (Gigantochloa Scortechinii) was hydrothermally treated in three different buffered media, namely alkaline, neutral and acidic medium. Response surface methodology (RSM) models were developed for the influences of treatment temperature, treatment duration and pH of buffered media on dimensional stability of Semantan bamboo. The models suggested that treatment temperature is the most crucial factor that led to improvement in dimensional stability. Lengthened treatment time also exerted noticeable influence when the temperature remained constant. More dimensionally stable samples were obtained in neutral and alkaline media.

Index Terms*: *buffered media, dimensional stability, hydrothermal treatment, Response Surface Methodology, Semantan bamboo

I. INTRODUCTION

Semantan bamboo (*Gigantochloa Scortechinii*) is a common and the most commercially utilized bamboo species in Malaysia [1]. With the new interest for structural applications, bamboo has now become a new sought-after material owing to it abundancy and fast-growing char-acteristic. However, like wood, dimensional instability of bamboo is one of the concerns in structural applications and therefore thermal treatment was proposed to improve its dimensional stability [2]. Heat treatment is an environmentally friendly method in improving the di-mensional stability of wood materials [1]. The primary effect of the treatment is better dimensional stability led by reduction in equilibrium moisture content [4-7]. Using water as heating medium, hydrothermal treatment is an economical way to enhance the dimensional stability of treated wood [8-9]. Hydrothermal treatment of beech wood has been conducted in acidic, neutral and alkaline buffered solutions by Talaei and Karimi et al. [10] and varied mechanical properties of the treated beech woods were reported. To the authors' knowledge, reports on the influence of hydrothermal treatment using different buffered mediums on the dimensional stability of bamboo are scarce. The current study aimed to improve the dimensional stability of bamboo using hydrothermal treatment with different buffered solutions (pH 5, 7 and 8) as heating medium. Response surface methodology (RSM) models for dimensional stability attributes, thickness swelling (TS) and water absorption (WA), of the hydrothermally treated bamboo were developed. pH of the buffered medium, treatment temperature and time were taken as independent variables.

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Zaidon Ashaari, Department of Forest Production, Faculty of Forestry, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.

Lee Seng Hua, Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia. *Corresponding author. Email: lee_seng@upm.edu.my*

Juliana Abdul Halip, Faculty of Technology Management and Business, Universiti Tun Hussien Onn, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

Syeed SaifulAzry Al Edrus, Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

Lum Wei Chen, Institute for Infrastructure Engineering and Sustainable Management (IIESM), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

Lee Ching Hao, Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

II. MATERIALS AND METHODOLOGY

A. Samples preparation

Semantan bamboo as raw material in this study were procured from Raub, a district located in Pahang, Malaysia. Only matured bamboo was chosen and harvested. The selection mode was random where the culms having diameter between 90 to 110 cm was selected. The selected bamboo stands were cut at a height of 30 cm from the ground. The bamboos were split into several parts before cutting into sizes of 50 mm x 50 mm x 10 mm (length x width x thickness). To prevent from attack by fungus and loss of moisture, the harvested samples were conditioned in a cold room with temperature of 4 °C.

B. Research Surface Methodology

Central composite design (CCD) using response surface methodology (RSM) was used in the present study to investigate the effects of treatment variables on dimensional stability of bamboo. Three independent variables, namely, buffered mediums (pH), treatment temperature (ºC) and treatment time (min) were selected and the response variable was thickness swelling (TS) and water absorption (WA). The CCD was conducted using Design Expert Software (State Ease, Design Expert 9). A 20-run CCD using RSM was developed. Experimental conditions of coded and actual values developed using RSM with CCD are shown in Table 1.

C. Treatment process

Hydrothermal treatment was conducted by boiling the bamboo in different buffered mediums ranging from pH 4 to 9 above the atmospheric pressure by using twin digesters. After loading the samples in the twin digesters, buffered solutions were subsequently heated up to the required temperature ranging from 60 - 160 °C as suggested by experimental conditions. After the respective required treatment times (13 to 147 min), the treated samples were taken out from the digester. The samples were then put in the oven at 100 ± 3 °C for 24 h for drying purpose. The samples were conditioned to a constant mass before the evaluation of properties were conducted. Conditioned samples were submerged in a beaker filled with distilled water. After 24 h, the TS and WA before and after immersion in water were determined and expressed in percentage.

TABLE 1: EXPERIMENTAL DESIGN OF HYDROTHERMAL TREATMENT VARIABLES USING CENTRAL COMPOSITE DESIGN

	Coded factor			Actual factor		
Run	X_1	X_2	X_3	pH	Temp (ºC)	Time (min)
1	-1	-1	-1	5	80	40
2	1	-1	-1	8	80	40
3	-1	1	-1	5	140	40
4	1	1	-1	8	140	40
5	-1	-1	1	5	80	120
6	1	-1	1	8	80	120
7	-1	1	1	5	140	120
8	1	1	1	8	140	120
9	-α	0	0	4	110	80
10	α	0	0	9	110	80
11	0	-α	0	6.5	60	80
12	0	α	0	6.5	160	80
13	0	0	-α	6.5	110	13
14	0	0	α	6.5	110	147
15	0	0	0	6.5	110	80
16	0	0	0	6.5	110	80
17	0	0	0	6.5	110	80
18	0	0	0	6.5	110	80
19	0	0	0	6.5	110	80
20	0	0	0	6.5	110	80

(CCD)

III. RESULTS AND DISCUSSION

From the experimental result, two quadratic equations (Equation 1 and 2) were obtained. Any coefficients that were statistically insignificant were deleted from the equation and the final equations in terms of actual factors are shown below:

$$TS = 33.48 - 1.10pH - 0.25Temp - 0.04Time + 0.00061Temp^2 + 000017Time^2 \quad (1)$$

$$WA = 153.50 - 0.90Temp - 0.34Time + 0.0016Temp^2 + 0.020\ pH\times Time + 0.0012\ Temp\times Time \quad (2)$$

To ensure the fitted model gave a sufficient approximation of the results obtained in the experimental conditions, adequacy of the model was evaluated. Insignificant lack-of-fit values of 0.6663 and 0.7172 for WA and TS, respectively indicated the appropriateness of the model for further investigation. The fit of the model was evaluated using coefficient of multiple regression (r^2) and adjusted r^2 was used for confirmation of the model adequacy. Based on the analysis, r^2 values of 0.9900 and 0.9862 for WA and TS, respectively, indicated a highly fitness of the model. The adequacy of the model was further proved by high adjusted r^2 of 0.9810 and 0.9738, respectively.

The effects of variables (pH, treatment temperature and time) on the response of thickness swelling (TS) and water absorption (WA) of the hydrothermally treated samples are presented in Figure 1. From the figure, one can see that the TS of bamboo decreased as the treatment temperature and time increased. The lowest TS of 3.88% was attained when subjected to 160 °C for 80 min while the highest TS of 13.26% was recorded when the samples treated at 60 °C for 80 min. Despite treatment time showed considerable influence on the TS values, treatment temperature is the most crucial factor among these two treatment variables. For example, bamboo samples treated at 140 °C for 40 min resulted in a TS of 5.96%. The resulted value was lower than the TS of bamboo samples (6.49%) that subjected to lower temperature but longer exposure time (110 °C for 147 min). In other words, treatment time could be shortened by more than 107 min when the treatment temperature was raised by 30 °C. The WA pattern mirrored that of TS with lower WA obtained with higher treatment temperature. Enhancement in dimensional stability is mainly attributed to the reduction of hygroscopicity of the hydrothermally treated samples. Olarescu et al. [11] stated that the hydroscopicity of thermally treated lime wood was reduced and the reduction increased along with increasing treatment temperature and time. Hemicelluloses and amorphous cellulose decomposed by thermal treatment are the main reason to led to the nature of treated wood become hydrophobic [12]. On the contrary, pH values of treatment medium were found did not significantly affect the dimensional stability of the treated samples. Nevertheless, when both treatment temperature and time remained constant, better TS and WA were observed in the samples treated in neutral and alkaline mediums (pH 6.5, 8 and 9). The findings were in agreement with Saliman et al. [9] who reported that the oil palm wood hydrothermally treated in alkaline medium exhibited lower TS than the samples treated in acidic medium. Ebadi et al. [13] also reported the highest anti-swelling efficiency (ASE) was observed in oil palm wood treated using buffered medium having pH of 8.

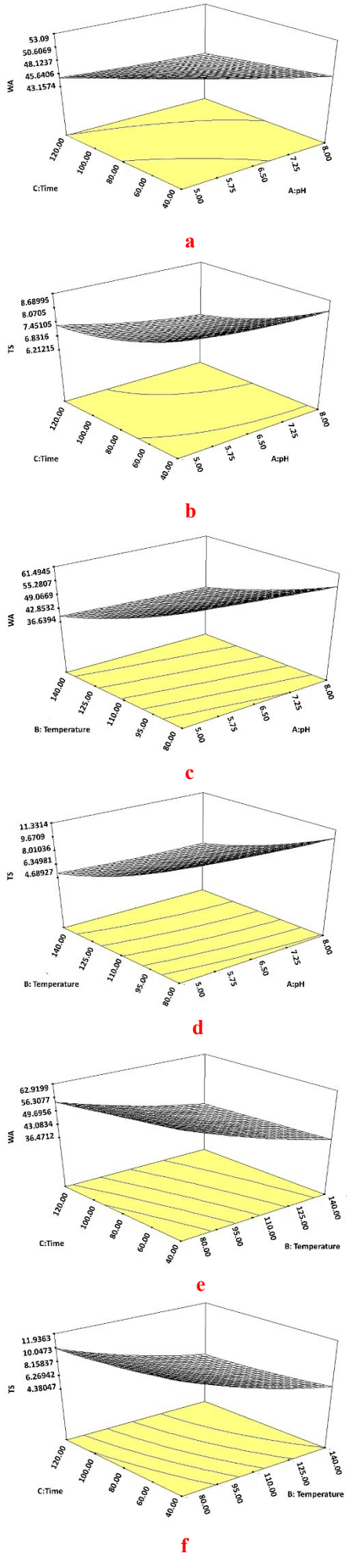

Fig. 1: 3D-surface plots of water absorption (WA) and thickness swelling (TS) as function of time and pH (a & b), temperature and pH (c & d) and time and temperature (e & f)

IV. CONCLUSIONS

In conclusion, better dimensional stability of Semantan bamboo could be attained by hydrothermal treatment. The RSM models suggesting that higher treatment temperature and time could resulted in lower TS and WA. Neutral and alkaline buffered mediums are preferred to en-hance the dimensional stability of bamboo to a higher extent. However, degree of temperature and time has to be carefully controlled by taking mechanical properties into consideration as it could be adversely affected by high temperature.

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REFERENCES

1. R. Anokye, E.S. Bakar, A.Y. Abare, R.M. Kalong, and A. Muhammad, "The difference in density along the bamboo culms of *Gigantochloa scortichinii* and *Bambusa vulgaris*," *Journal of Emerging Technology and Advanced Engineering,* vol.4, 2014, pp. 638-643.
2. R.N. Borthakur, and P.K. Gogoi, "Studies of dimensional stability, thermal stability and biodegradation resistance capacity of chemi-cally treated bamboo," *Asian Journal of Biochemistry*, vol.9, 2014, pp. 16-29.
3. D. Sanberg, P. Haller, and P. Navi, "Thermo-hydro and thermo-hydro-mechanical wood processing: An opportunity for future envi-ronmentally friendly wood products," *Wood Material Science and Engineering*, vol.8, 2013, pp. 64-88.
4. S.H. Lee, Z. Ashaari, A.F. Ang, A.H. Juliana, W.C. Lum, R. Dahali, and R. Halis, "Effects of two-step post heat-treatment in palm oil on the properties of oil palm trunk particleboard," *Industrial Crops and Products*, vol. 116, 2018, pp. 249-258.
5. S.H. Lee, Z. Ashaari, W.C. Lum, A.F. Ang, A.H. Juliana, and R. Halis, "Chemical, physico-mechanical properties and biological durability of rubberwood particleboards after post heat-treatment in palm oil," *Holzforschung* vol.72, 2018, pp. 159-167.
6. S.H. Lee, Z. Ashaari, W.C. Lee, A.H. Juliana, A.F. Ang, L.P. Tan, K.L. Chin, and P.M. Tahir, "Thermal treatment of wood using vegetable oils: A review," *Construction and Building Materials*, vol.181, 2018, pp. 408-419.
7. J. Zhan, and S. Avramidis, "Needle fir wood modified by surface densification and thermal post-treatment: hygroscopicity and swelling behavior," *European Journal of Wood and Wood Products*, vol.74, 2016, pp. 49-56.
8. B.F. Tjeerdsma, and H. Militz, "Chemical changes in hydrothermal treated wood: FTIR analysis of combined hydrothermal and dry heat-treated wood,". *Holz als Roh- und Werkstoff*, Vol.63, 2005, pp. 102-111.
9. M.A.R. Saliman, Z. Ashaari, E.S. Bakar, S.H. Lee, P.M. Tahir, A.H. Juliana, and N.F. Leemon, "Hydrothermal treatment of oil palm wood: effect of treatment variables on dimensional stability using Response Surface Methodology," *Journal of Oil Palm Research*, vol.29, 2017, pp.130-135.
10. A. Talaei, and A. Karimi, "Mechanical properties of hydrothermally treated beech wood in buffered mediums," IRG/WP 12-40597, The International Research Group on Wood Preservation, 2012, Kuala Lumpur.
11. M.C. Olarescu, M. Campean, M. Ispas, and C. Cosereanu, "Effect of thermal treatment on some properties of lime wood,". *European Journal of Wood and Wood Products*, vol.72, 2014, pp. 559-562.

12. K.K. Pandey, S.V. Kumar, and K. Srinivas, "Inhibition of leaching of water soluble extractives of *Pterocarpus marsupium* by heat treatment," *European Journal of Wood and Wood Products*, vol.74, 2016, pp. 223-229.
13. S.E. Ebadi, A. Karimi, A.C.Y. Choo, Z. Ashaari, H.R. Naji, M. Soltani, and S.M. Anuar Ridzuan, "Physical behavior of Hydro-thermally treated oil palm wood in different buffered pH media," *BioResources*, vol.10, 2015, pp. 5317-5329.

AUTHORS PROFILE

Zaidon Ashaari is a professor from Faculty of Forestry, Universiti Putra Malaysia. His area of expertise is in wood treatment. To date, he has published more than 180 articles in numerous journals, book chapters, proceedings etc.

Lee Seng Hua is a research fellow from Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, majoring in wood science and technology. To date, he has published more than 80 articles in numerous journals, book chapters, proceedings etc.

Juliana Abdul Halip is a lecturer from Faculty of Technology Management and Business, Universiti Tun Hussien Onn, majoring in biocomposite science. To date, she has published more than 40 articles in numerous journals, book chapters, proceedings etc.

Syeed SaifulAzry Al Edrus is a research officer from Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, majoring in nanocomposite science. To date, he has published more than 20 articles in numerous journals, book chapters, proceedings etc.

Lum Wei Chen is a post-doctoral researcher from Institute for Infrastructure Engineering and Sustainable Management (IIESM), Universiti Teknologi MARA, majoring in wood science and technology. To date, he has published more than 20 articles in numerous journals, book chapters, proceedings etc.

Lee Ching Hao is a post-doctoral researcher from Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, majoring in biocomposite science. To date, he has published more than 10 articles in numerous journals, book chapters, proceedings etc.