Optimum condition of manufacturing hybrid particleboard from mixture of cocoa pod husk and bamboo particles

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ABSTRACT

This study was to investigate the feasibility of using cocoa pod husks (CPH) and bamboo in manufacturing hybrid particle board. Three-layer experimental particleboards from mixture of bamboo and CPH participles were manufactured using different surface to core layer ratios (30, 40 and 50%) and various UF ratios for surface layer (6, 8 and 10%) and for core layer (4, 6 and 8%). Modulus of rupture (MOR), internal bond strength (IB) and thickness swelling (TS) properties of the boards were evaluated based on Standard TCVN7756:2007 Test Methods for general purpose used in dry conditions. The results showed that boards in all ratios of surface to core layer investigated could be manufactured using up till 8% UF resin for surface layer and up till 6% UF resin for core layer without falling below the minimum Standard VN7754:2007. The optimal condition was the surface to core layer ratio of 30% used with 9.51% UF resin for surface layer and 7.45% UF resin for core layer obtaining the lowest thickness swelling (TS) 11.13%. The highest values of MOR and IB were 15.25 MPa and 0.45 MPa, respectively. This study demonstrates that cocoa pod husks and bamboo waste can be an alternative raw material source for particleboard production.

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1. Introduction

The abundance of agricultural residues has stimulated new interests in using agricultural fibres for global panel industries because of their environmental and profit able advantages (Rowell et al., 1997). Selection of agricultural residues have been successfully used in particleboard manufacturing (Ciannamea et al., 2010) and recent advances in the particleboard and recent advances in the particleboard industry show a bright outlook for bio-based particleboards (Bowyer et al., 2001; Pham, 2010). Non-wood plants as well as agro-based residues have been evaluated as raw materials for particleboard manufacture such as bamboo (Hoang, 2002; Nurhazwani et al., 2016), bagasse, corn stalks (Guler et al., 2016), cashew nut shell (Bui et al., 2010), chili pepper stalks (Oh & Yoo, 2011), jatropha shell (Tran, 2012), kenaf (Abdul et al., 2014), sunflower stalks (Guler et al., 2006), walnut shell (Hamidreza et al., 2012), wheat and rice straw (Li et al., 2010), etc. Bamboo has become a main material for the industrial manufacturing of furniture, parquet, and construction in recent years. Vancai (2010) pointed out that the conversion of bamboo into strips had average potential output up to 34.4%. Utilization of biomass byproduct from bamboo processing industry as value added products is an important issue to support the zero emission concepts.

Cocoa tree is an important and the most widely planted crops in several tropical countries. In Vietnam, Cocoa trees have been planted and growing in abundant numbers recently. In the cocoa industry, Cocoa pod husks (CPH) are treated as by-product of the mature cocoa pod, after obtaining the cocoa beans. In general, CPH accounts for up to 76% of the cocoa pod wet weight. Every ton of dry cocoa been produced will generate ten tons of cocoa pod husk as waste (Cruz et al., 2012). The resource of CPH is readily abundant but does not have marketable value and most of the CPH is discarded as waste or as compost for cocoa farming the ecological impact.

Particleboard made from mixing bamboo and wood as well as agricultural residues provide satisfactory results in terms of strength properties and also address raw material scarcity issues for the particleboard industries (Nurhazwani et al., 2016; De et al., 2017). Our previous study on singer-layer particle board from mixing bamboo and cocoa pod husks has shown that the boards can produced successfully with proper mixing ration of CPH to bamboo and UF resin. In this paper, the producing three-layer particle board is investigated with different ratios of surface and core layers and various ratio of UF resin.

2. Materials and Methods

2.1. Response Surface Methodology (RSM) and Central Composite Design

Central composite design (CCD) using RSM was used in the present study to investigate the effects surface layers ratios and resin ratios on physical and mechanical properties of particle board. Three independent variables, namely, surface layers ratios (%), and urea-formaldehyde (UF) resin ratios (%) for surface and core layers were selected and the response variable names were thickness swelling (TS), Modulus of Rupture (MOR) and Internal Bond (IB). The CCD was conducted using JMP 10.0. A 15-run CCD using RSM was developed and the ranges of the variables are shown in Table 1. Each of the independent variable was coded by five different levels as shown in Table 1, where surface layers ratios (%) and resin ratios (%) for surface and core layers ranged from 30% to 50%, 6 to 10% and 4 to 6%, respectively.

2.2. Manufacturing three-layer particle board

Bamboo waste and CPH were provided from Bamboo Nature Company in Binh Duong and Thanh Dat Cocoa Company in Ba Ria Vung Tau Province. They were chipped using a hacker chipper before the chips were reduced into smaller particles using a knife ring flaker. The particles were sorted using a circulating vibrator screen to separate the particles into various particle sizes retained at 0.5, 1.0, 2.0 mm and 4 mm sieve sizes. Particles of sizes 0.5 to 2.0 mm for the surface layer and particles of sizes 2 to 4 mm for the core layer were used. The particles were dried in an oven maintained at 80°C until moisture content of 6% was reached.

Three-layer particle boards with size of 300 × 300 × 11 mm and a medium density were produced from mixture of 30% CPH and 70% bamboo particles for both surface and core layers. The particle boards were investigated with different ratios of surface to core layers (30, 40 and 50%) and various ratio of UF resin for surface layer (6, 8 and 10%) and for core layer (4, 6 and 8%) as suggested by RSM models (Table 1). The boards were pressed under a temperature of 140oC, pressure of 2.7 MPa for 9 min. Three replications for each run were done, total 45 boards produced.

2.3. Testing the particle boards investigated

The boards were conditioned at ambient temperature and 65% relative humidity until they achieved equilibrium moisture content prior to cutting into test specimens. The samples for testing and the internal bond (IB) and modulus of rupture (MOR) were determined according to procedure Standard TCVN 7756:2007. Thickness swelling (TS) properties of the panels were investigated 24-h soaking test.

3. Results and Discussion

3.1. Properties three-layer particle board investigated

The results of the properties of the particle board investigated are presented in Table 2. The boards in nine experiments (Runs 2-5, Runs 8-10, Run 13 and Run 15) meet the Standard TCVN 7754:2007 required for the modulus of rupture ($\geq$ 12.5 MPa) and the internal bond ($\geq$ 0.28 MPa).

Table 1. The range and levels of the variables

Factor	Variable	Range and level of actual and coded values				
		-α	-1	0	+1	α
X_1	Surface layers ratios (%)	30	30	40	50	50
X_2	Resin ratios for surface layers (%)	6	6	8	10	10
X_3	Resin ratios for core layer (%)	4	4	6	8	8

Table 2. Properties of the particle boards investigated

Run	Surface layers ratios (%)	Resin ratios for surface layers (%)	Resin ratios for core layer (%)	TS[1] (%)	MOR[2] (MPa)	IB[3] (MPa)
1	30	6	4	13.24	13.85	0.26
2	30	6	8	11.51	14.72	0.36
3	30	8	6	11.44	15.01	0.42
4	30	10	4	12.55	14.17	0.35
5	30	10	8	11.41	15.09	0.43
6	40	6	6	12.46	14.10	0.25
7	40	8	4	13.80	13.47	0.27
8	40	8	6	12.33	14.49	0.35
9	40	8	8	12.15	14.83	0.37
10	40	10	6	11.86	14.36	0.36
11	50	6	4	13.92	12.06	0.23
12	50	6	8	13.52	12.22	0.25
13	50	8	6	12.97	13.08	0.34
14	50	10	4	13.82	12.38	0.30
15	50	10	8	12.75	13.14	0.35

[1]TS: Thickness swelling
[2]MOR: Modulus of rupture.
[3]IB: Internal bond.

3.2. Effects of surface to core layers ratio and resin ratios for the layers on properties of particle board

Statistical analysis showed a highly significant effect of the ratio of layers and ratio of UF used in each layer for TS, MOR and IB of the three-layer particle boards tested (Figures 1, 2 and 3).

Thickness swelling (TS): Figure 1 shown that TS is inversely proportional to surface layers ratios and directly proportional to resin ratios for surface and core layer. In which surface layers ratios factors has the greatest influence on TS. When applying surface layers ratios below 31% with resin ratios for surface layers above 9% and resin ratios for core layer 6%, TS has the highest value of 11.41%.

Modulus of Rupture (MOR): In Figure 2, MOR increase as the surface layers ratios decreased with increasing of UF resin for the layers. The MOR has the highest value of 15.09 MPa, when applying surface layers ratios below 32.2% with UF resin for surface above 7.1% and for core layer 6.2%. The board manufactured applying all layer investigated ratios and using up till 8% UF resin for surface layer and up till 6% UF resin for core layer as well as using 30% and 40% surface layer, 6% UF resin for surface layer and 4% UF resin for core layer satisfy the Standard TCVN 7754:2007 (MOR $\geq$ 12.5 MPa).

Internal Bond (IB): Figure 3 shown that IB of the board increase when UF resin for both layers increased and the Surface layer ratios decreased. At the surface layers ratios below 30.9%, using UF above 7.6% for the surface layer and 6.7% for the core layer, the result obtains the highest IB of 0.43 MPa. The board manufactured at all layer ratios and using up till 8% UF resin for surface layer and up till 6% UF resin for core layer as well as using 30% surface layer, 6% UF resin for surface layer and 8% UF resin for core layer and 10% UF resin for surface layer and 4% UF resin for core layer satisfy the Standard TCVN 7754:2007 (IB $\geq$ 0.28 MPa).

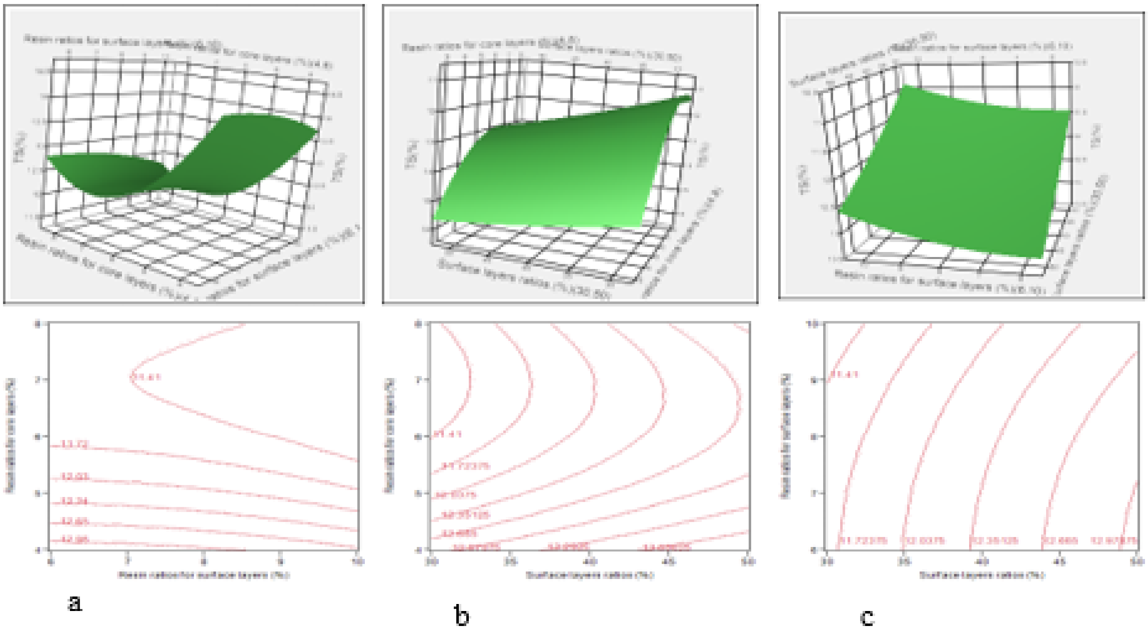

Figure 1. The 3D-surface plots of thickness swelling (TS) as function of (a) Resin ratios for surface layers and resin ratios for core layer (b) Surface layers ratios and resin ratios for core layer (c) Surface layers ratios and resin ratios for surface layers.

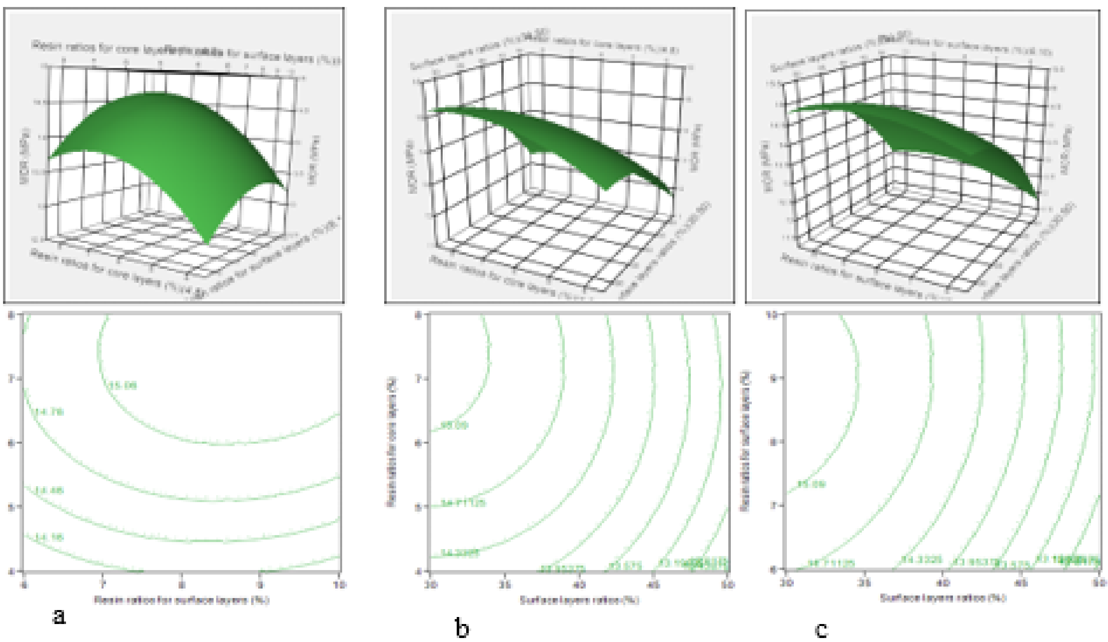

Figure 2. The 3D-surface plots of MOR as function of (a) Resin ratios for surface layers and resin ratios for core layer (b) Surface layers ratios and resin ratios for core layer (c) Surface layers ratios and resin ratios for surface layers.

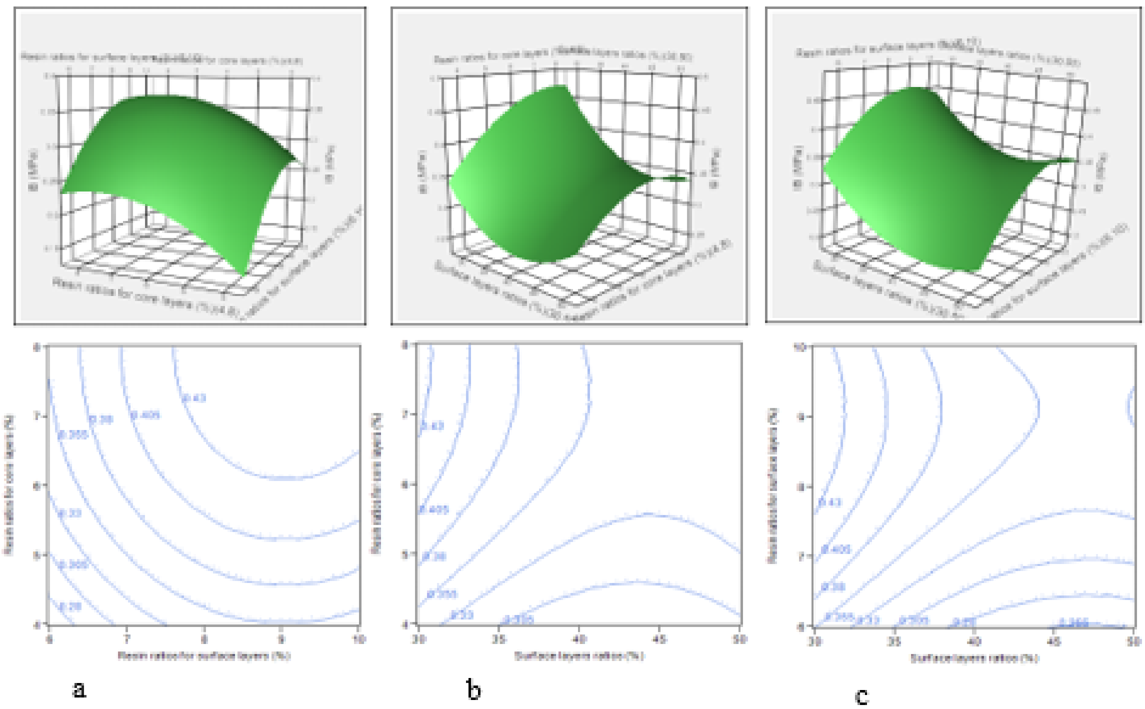

Figure 3. The 3D-surface plots of IB as function of (a) Resin ratios for surface layers and resin ratios for core layers (b) Surface layers ratios and resin ratios for core layers (c) Surface layers ratios and resin ratios for surface layers.

3.3. Regression and Adequacy of the Model and optimal condition

To ensure the fitted model gave a sufficient approximation of the results obtained in the experimental conditions, the adequacy of the model was evaluated. The fit of the model was evaluated using coefficient of multiple regressions (R^2) and adjusted R^2 was used for confirmation of the model adequacy. Based on the analysis, R^2 values of 0.9666, 0.9832 and 0.9769 for the TS, MOR and IB, respectively, indicated high fitness of the model. The adequacy of the model was further proved by high adjusted R^2 of 0.9068, 0.9529 and 0.9354, respectively. Describing the functional relation of the independent variables (X_1: surface layer, X_2: UF resin ratio for surface layer and X_3: UF resin ratio for core layer) and the response variable using regression analysis obtain three models. The final equations in terms of actual factors are shown below:

Y_{TS} (%) $= 18.681 + 0.0683x_1 - 0.113x_2 - 2.4478x_3 + 0.1790x_3^2$

Y_{MOR} (MPa) $= 9.3339 + 0.2524x_1 + 0.1095x_2 + 0.2035x_3 - 0.0044x_1^2$

Y_{IB} (MPa) $= 0.205 - 0.0355x_1 + 0.182x_2 + 0.0175x_3 + 0.0004x_1^2 + 0.01x_2^2$

The optimal condition was computed by the responsive surface response method, resulting shown as Figure 4. The optimal condition is 30% surface layers ratios, 9.51% resin ratios for surface and 7.45% resin ratios core layer obtaining the lowest TS 11.23%, the highest value of MOR and IB is 15.25 MPa and 0.45 MPa, respectively.

4. Conclusions

Results show that it is possible to produce particleboards using mixture of cocoa pod husk particles and bamboo particles using urea formaldehyde resin. The boards manufactured using up till 8% UF resin for surface layer and up till 6% UF resin for core layer meet the Standard TCVN7754:2007 required for the modulus of rupture ($\geq$ 12.5 MPa) and the internal bond ($\geq$ 0.28 MPa). The board has the lowest TS 11.23% and the highest value of MOR 15.25 MPa and IB 0.45

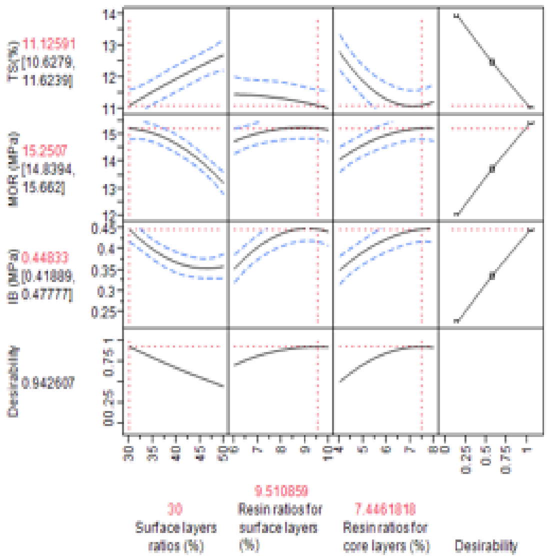

Figure 4. The cross-sectional surface meets the optimum point.

MPa, applying 30% surface layers ratios, 9.5% resin ratios for surface and 7.5% resin ratios core layer. The results of this study notably states that cocoa pod husks and bamboo waste are as an alternative renewable materials and feasible for particle board production.

References

Abdul, H. J., Paridah, M. T., Adrian, C. Y. C., & Zaidon, A. (2014). Effect of Kenaf parts on the performance of single-Layer and three-layer particleboard made from Kenaf and Rubberwood. *BioResources* 9(1), 1401-1416.

Bowyer, J. L., & Stockman, V. E. (2001). Agricultural residues: an exciting bio-based raw material for the global panel industry. *Forest Products Journal* 51(1), 10–21.

Bui, A. V., Nguyen, Q. V., & Pham, M. T. T. (2010). Research on utilizing cashew nut cover and Eucallyptus urophylla chip for common particle board producing. *Vietnam Journal Forest Science* 3, 1383-1387.

Ciannamea, E. M., Stefani, P. M., & Ruseckaite, R. A. (2010). Medium-density particleboards from modified rice husks and soybean protein concentrate-based adhesives. *Bioresource Technology* 101, 818–825.

De, A. A. C., Victor, A., De, A., Elen, A. M. M., Maristela, G., Rafaele, A. M., José, N. G., & Juliana, C. B. (2017). Wood-bamboo particleboard: Mechanical properties. *BioResources* 12(4), 7784-7792.

Guler, C., Bektas, I., & Kala Y. H. (2006). Properties of particleboard from sunflower stalks (*Helianthus annuus* L.) and Calabrian pine (*Pinus brutia* Ten). *Forest Products Journal* 56, 56–60.

Guler, C., Halil I. S., & Sevcan, Y. (2016). The potential for using corn stalks as a raw material for production particleboard with industrial wood chips. *Journal of Wood Research* 61(2), 299-306.

Hamidreza, P. , Abolghasem, K., & Taghi, T. (2012). The potential for using walnut (*Juglans regia*) shell as a raw material for wood-based particleboard manufacturing. *Composites: Part B* 43, 3276–3280.

Hoang, H. T. (2002). *Study on producing board from combining Balcooa bamboo and Rubber wood* (Unpublished doctoral dissertation). Vietnamese Academy of Forest Sciences, Ha Noi, Vietnam.

Li, X., Chi, Z., Winandy, J. E., & Basta, A. H. (2010). Selected properties of particleboard panels manufactured from rice straws of different geometries. *Bioresource Technology* 101, 4662–4666.

Nurhazwani, O., Jawaid, M., Paridah, M. T., Abdul, J. H., & Hamid, S. A. (2016). Hybrid particleboard made from bamboo (*Dendrocalamus asper*) veneer and Rubber wood (*Hevea brasinesis*). *BioResources* 11(1), 306-323.

Pham, N. N. (2010). Study on the production process parameters of particle board from agricultural residues. *Journal of Forestry Science and Technology* 1, 78-82.

Rowell R. M, Anand R., Claufield F. D, & Jacobson E. R. (1997). Utilization of natural fibers in plastic composites, problems and opportunities. *Journal of Thermoplastic Composites Materials* 15(4), 281-300.

Tran, C. V. (2012). Study on producing particle board from Rubber wood and Jatropha shells. *Journal of Forestry Science and Technology* 1, 88-95.

Vancai, L. (2010) Physical and mechanical properties of particleboard from bamboo waste. *World Academy of Science, Engineering and Technology* 40, 566–570.

Oh, Y. S., & Yoo, J. Y. (2011). Properties of particleboard made from chili pepper stalks. *Journal of Tropical Forest Science* 23(4), 473–477.