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Head – office
Journal of Forestry Science and Technology Department
Vietnam National University of Forestry
Chuong My – Ha Noi – Viet Nam
Tel: 024.8588.3318
Email: Tapchikhcnln@vnuf.edu.vn

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Xuân Mai – Chương Mỹ – Hà Nội
ĐT: 024. 8588. 3318
Email: Tapchikhcnln@vnuf.edu.vn

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MỤC LỤC

INVESTIGATION ON PRODUCING SINGLE-LAYER PARTICLEBOARD FROM BAMBOO WASTE AND COCOA POD HUSKS

Tang Thi Kim Hong[1*], Nguyen Duy Linh[1]
[1]*Nong Lam University of Ho Chi Minh City*

SUMMARY

Agricultural residues are the potential sources for producing bio-composite. Cocoa pod husk (CPH) is a waste material from cocoa industry. The objective of this project is to investigate the feasibility of using cocoa pod husks and bamboo waste for manufacturing hybrid particleboard. Chemical compositions of CPH were determined based on TAPPI Standard Test Methods resulting the cellulose of 29%, hemicellulose of 30%, lignin of 28% and ash content of 9%. Singe-layer particleboards containing different CPH/bamboo particle ratios (16%, 20%, 30%, 40% and 44%) were made using various urea–formaldehyde (UF) resin ratios (2%, 3%, 6%, 9% and 10%). The results indicated that panels produced by using mixing ratio of CPH particles up to 30% with up till 6% UF resin fulfilled the required standard TCVN7754:2007 for modulus of rupture (MOR) and internal bond (IB). The optimal condition is 30.6% CPH particle and 8.1% UF resin obtaining the lowest thickness swelling (TS) 13.2%, the highest value of MOR and IB is 13.1 MPa and 0.33 MPa respectively. The investigations stated cocoa pod husks and bamboo waste as alternative raw materials are feasible for particleboard production.

Keywords: Bamboo, Cocoa pod husk, particleboard, physical mechanical properties.

1. INTRODUCTION

Sustainable agricultural residues are potential sources of raw materials for the manufacture of bio-based panel products. The abundance of agricultural residues has stimulated new interests in using agricultural fibres for global panel industries because of their environmental and profitable 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 industry show a bright outlook for bio-based particleboards (Bowyer et al., 2001; Pham Ngoc Nam, 2010). Non-wood plants as well as agro-based residues have been evaluated as raw materials for particleboard manufacture such as bamboo, kenaf, palm trunk, wheat and rice straw, bagasse, corn stalks, chili pepper stalks, rice husk, cashew nut shell, jatropha shell, etc. (Nurhazwani et al., 2016; Hoang Thanh Huong, 2002; Tran Van Chu, 2012; Bui Van Ai et al., 2010, Gueler et al., 2006 and 2016, Li et al., 2010, Hamidreza Pirayesh et al., 2012, Gueler et al., 2016, YS Oh & JY Yoo, 2011. Abdul Halip et al., 2014).

**Corresponding author: tangkimhong@hcmuaf.edu.vn*

In recent years, bamboo has become a main material for the industrial manufacturing of furniture, parquet, and construction. Vancai (2010) pointed out that the conversion of bamboo into strips had average potential output up to 34.4%. Utilization of biomass by-product from bamboo processing industry as value added products is an important issue to support the zero emission concepts.

Cocoa 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 (IRC, 2013). 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. In order to contribute to adding value and solving environmental pollution, the study on the feasibility of cocoa pod husk and bamboo waste for bio-based board was carried out. The work aims to determine chemical composition of cocoa pod husk, and investigate the physical and mechanical properties of singe-layer particleboard using different mixing ratios of Cacao pod husk particles and various ratios of UF resin.

2. RESEARCH METHODOLOGY

Chemical analysis of cocoa pod husk

Chemical composition of cocoa pod husks was done according to TAPPI Standard Test Methods. The amount of cellulose and hemicellulose were assessed by TAPPI T203, whereas lignin and ash content determined by TAPPI T 222 Om-06 and T 211 Om-07, respectively.

Response Surface Methodology (RSM) and Central Composite Design

Central Composite Design (CCD) using RSM was used in the present study to investigate the effects of treatment variables on physical and mechanical properties of particleboard. Two independent variables, namely, CPH/bamboo particle ratios (%), and urea-formaldehyde (UF) resin ratios (%) were selected and the response variables were thickness swelling (TS), modulus of rupture (MOR) and internal bond (IB). The CCD was conducted using JMP 10.0. A 9-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 CPH/bamboo particle ratios and resin ratios ranged from 20 to 40% and 3 to 9%, respectively.

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	CPH/bamboo ratios (%)	16	20	30	40	44
X_2	Resin ratios (%)	2	3	6	9	10

Manufacturing single-layer particleboard

Bamboo waste and CPH were provided from Bamboo Nature Company, Binh Duong and Thanh Dat Cocoa Company, 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 and 2.0 mm sieve sizes. Only particles of sizes > 0.5 to < 2.0 mm were used. The particles were dried in an oven maintained at 80°C until moisture content of 6% was reached.

Single-layer particleboards of 330 × 330 × 11 mm in size with a medium density were produced from mixture of the bamboo and CPH particles with urea formaldehyde resin. The particleboards were investigated with CPH/bamboo particle ratios ranging from 20-40% and UF resin ratios from 3-9% as suggested by RSM models (Table 1). The boards were pressed under a temperature of 140°C, pressure of 2.5 MPa for 9 min. Three replications for each run were done, total 27 boards produced.

Testing particleboards

The boards were conditioned at ambient temperature and 65% relative humidity until they achieved equilibrium moisture content prior to cutting into test specimens. The internal bond (IB) and modulus of rupture (MOR) were determined according to procedure Standard VN7756:2007. Thickness swelling (TS) properties of the panels were investigated 24-hour soaking test.

The specimens of 270 × 50 × 11 mm in size for MOR testing and the specimens of 50 × 50 × 11 mm for IB and TS were applied. Two replications for each board were done, total 54 specimens taken for each testing.

3. RESULTS AND DISCUSSION

Chemical analysis of cocoa pod husk

The chemical composition of the cocoa pod husk investigated is described in Table 2, which includes the corresponding data from previous studies for the sake of comparison.

Table 2. Chemical composition of cocoa pod husk and comparison with other lignocellulose materials (%, w/w, oven dried)

Components	Cocoa Pod Husk [This investigation]	Cocoa Pod Husk *	Bamboo **	Rubber wood ***
Cellulose	29.3	30.8	49.1	40.1
Hemicellulose	29.9	21.1	19.6	28.7
Lignin	28.1	25.6	17.1	19.0
Ash	9.3	-	1.8	1.1

* (Nivio et al., 2018), ** (Liese et al., 2014), *** (Jirawat et al., 2015)

The chemical analysis result of cocoa pod husk in this investigation is slightly different with the study of Nivio et al., (2018). Rubber wood has popularly been used in wood-based board industry, Vietnam. Comparing the chemical composition of the cocoa husk to bamboo and Rubber wood revealed that cocoa pod husk presents the content of cellulose and hemicellulose is negligible lower, whereas the lignin of CPH is notability higher. Consequently, the contents of CPH in cellulose of 29.7%, hemicellulose of 28.2% and lignin of 28.1% are acceptable for applying particleboard, especially mentioned for producing CPH particleboard using a lower adhesive content.

Single-layer particleboard investigated

Results of properties of the particleboard investigated were given in Table 3. The boards were done at two runs 5 and 6 (ratio of 30% CPH with 6% UF and 30% CPH with 10% UF), which meet the Standard VN 7754:2007 required for the modulus of rupture (≥ 12.5 MPa) and the internal bond (≥ 0.28 MPa).

Table 3. Properties of particleboard investigated

Run	CPH/bamboo ratios (%)	UF Resin ratios (%)	TS (%)	MOR (MPa)	IB (MPa)
1	16	6	16.81	9.64	0.19
2	20	3	17.21	10.20	0.14
3	20	9	14.91	11.76	0.27
4	30	2	16.76	9.96	0.14
5	30	6	13.43	12.82	0.30
6	30	10	13.26	13.02	0.35
7	40	3	16.67	12.10	0.20
8	40	9	15.68	12.70	0.24
9	44	6	15.70	12.40	0.18

Effects of CPH/bamboo and UF resin ratios on mechanical properties of particleboard

Ratio of CPH to bamboo and ratio of UF significantly influence on TS, MOR and IB of the singe-layer particleboards tested, shown as Figures 1, 2 and 3.

Fig.1 shown that boards manufactured at CPH/bamboo ratios of 27 to 32% with UF resin ratio 6.3 to 8.7% are obtained the lowest TS of 13.26%. When the CPH/bamboo ratios obtain 16 - 27%, TS is decreased, whereas CPH/bamboo ratios are above 32% resulting TS increased.

In Fig.2 Modulus of Rupture (MOR) is directly proportional to CPH/bamboo ratios and resin ratios. In which CPH/bamboo ratio factor has the greatest influence on MOR. The MOR has the highest value of 13 MPa when applying CPH/bamboo ratios 29 - 40% with UF ratios above 6%. The boards produced at 30% CPH with 6% UF, 30% CPH with 10% UF and 40% CPH, 9% UF were obtained MOR>12.5 MPa satisfied the Standard VN 7754:2007 (≥ 12.5 MPa).

Difference of MOR among particleboards resulted from slenderness ratio (SL) of particles and Kelly (1977) proved that the MOR properties also vary in the percentage of raw materials. Cell wall thickness and fiber length has great impact on improving MOR properties. The CPH particles have a lower fiber length than bamboo particles. Consequently, low MOR may be found for the hybrid particleboards having a higher percentage of CPH. This result is confirmed by previous studies of Hasan et al. (2015), Bui Van Ai et al. (2010) and Islam et al. (2006).

Fig.3 shown that boards manufactured at CPH/bamboo ratios 24 - 32% with UF ratios above 7.4% indicate the highest IB of 0.32 MPa. When the CPH/bamboo ratios obtain 16-24%, IB is increased, whereas CPH/bamboo ratios are above 32.1% resulting IB decreased. The boards produced at 30% CPH with 6% UF and 30% CPH with 10% UF were obtained IB>0.28 MPa and satisfied the Standard VN 7754:2007 (≥ 0.28 MPa).

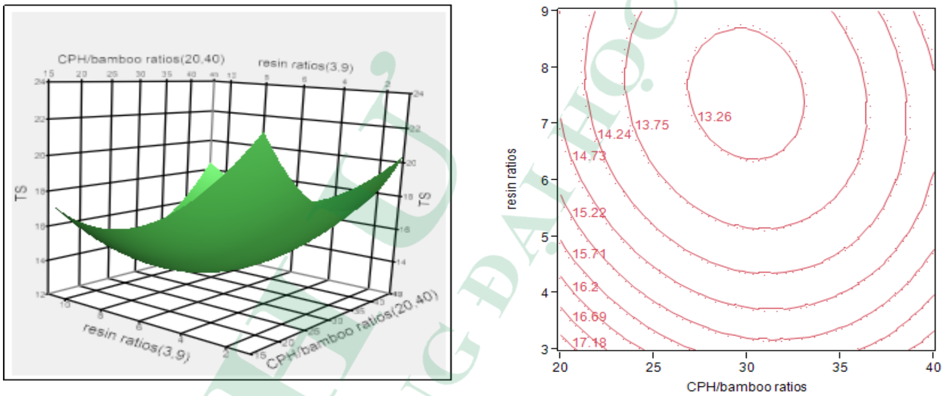

Figure 1. The 3D-surface plots of TS as function of CPH/bamboo ratios and resin ratios

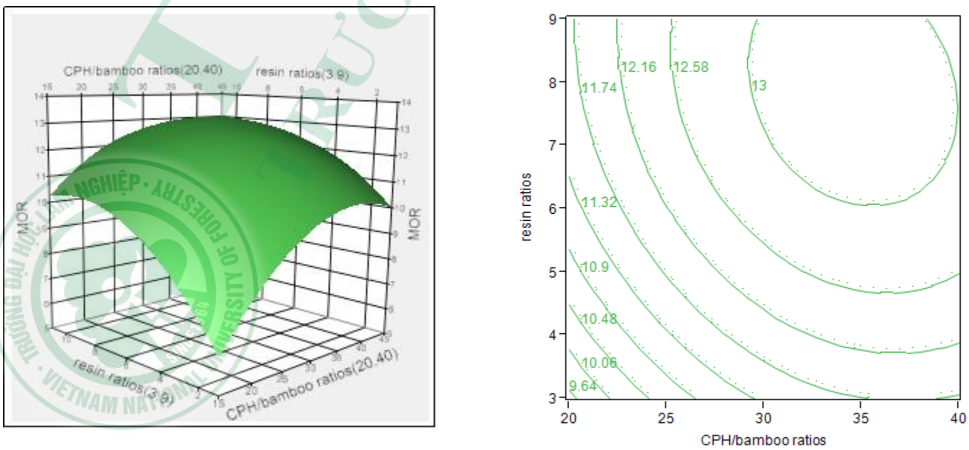

Figure 2. The 3D-surface plots of MOR as function of CPH/bamboo ratios and resin ratios

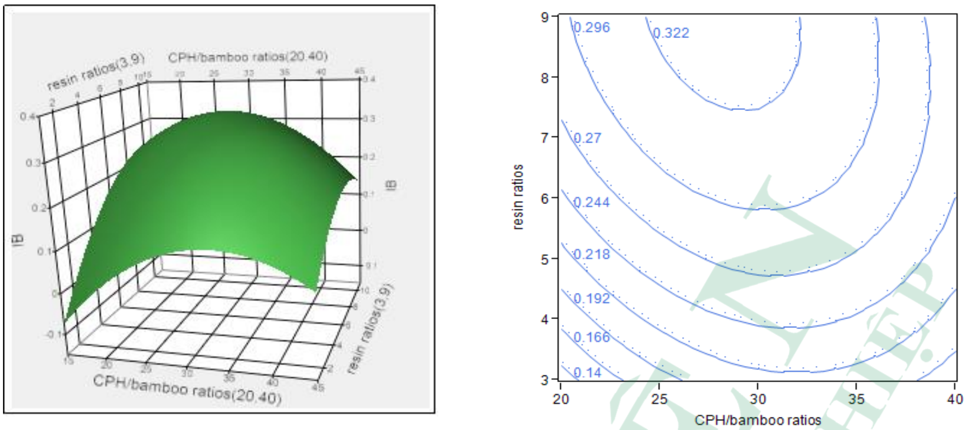

Figure 3. The 3D-surface plots of IB as function of CPH/bamboo ratios and resin ratios

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 0.9364, 0.9026 and 0.9348 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 0.8305, 0.7403 and 0.8262, respectively. Describing the functional relation of the independent variables (X_1: CPH/bamboo particle ratio and X_2: UF resin ratio) and the response variable using regression analysis obtain three equations. The final equations in terms of actual factors are shown below:

Y_{TS} (%) = $29.4384 - 0.93x_1 - 0.351x_2 + 0.0155x_1^2$

Y_{MOR} (MPa) = $8.5555 + 0.0847x_1 + 0.2753x_2$

Y_{IB} (MPa) = $-0.3475 + 0.035x_1 + 0.0199x_2 - 0.0006x_1^2$

Optimal condition was computed by the response surface method, resulting 30.62% CPH particle and 8.1% UF resin obtaining the lowest TS 13.15%, the highest value of MOR and IB is 13.01 MPa and 0.33 MPa, respectively.

4. CONCLUSIONS

This study investigated the feasibility of using cocoa pod husk particles in the manufacturing one- layer particleboard. The results show that it is possible to produce particleboards using mixture of cocoa pod husk particles and bamboo particles while using urea formaldehyde as the binder. Boards using 30% CPH with 6% UF and 30% CPH with 10% UF meet the Standard VN 7754:2007 required for modulus of rupture (MOR) and internal bond (IB).

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NGHIÊN CỨU SẢN XUẤT VÁN DĂM MỘT LỚP TỪ PHẾ LIỆU TRE VÀ VỎ QUẢ CA CAO

Tăng Thị Kim Hồng[1], Nguyễn Duy Linh[1]

[1]*Trường Đại học Nông Lâm TP. Hồ Chí Minh*

TÓM TẮT

Các phế liệu nông nghiệp có thể là một trong những nguồn nguyên liệu bổ sung hoặc thay thế cho xơ sợi gỗ để sản xuất ván composite sinh học. Vỏ quả Ca cao là nguồn phế liệu có khối lượng lớn từ công nghiệp chế biến hạt Ca cao. Mục tiêu của nghiên cứu là thử nghiệm khả năng sản xuất ván dăm hỗn hợp từ vỏ quả Ca cao và phế liệu tre. Thành phần hóa học của vỏ quả Ca cao được xác định theo tiêu chuẩn TAPPI. Kết quả phân tích cho thấy hàm lượng Cellulose là 29%, Hemicellulose 30%, Lignin 28% và hàm lượng tro 9%. Ván thực nghiệm là ván dăm một lớp được nghiên cứu với những tỷ lệ phối trộn giữa dăm vỏ Ca cao và dăm tre: 16%, 20%, 30%, 40% và 44% với tỷ lệ keo UF: 2%, 3%, 6%, 9% và 10%. Kết quả đã chỉ ra rằng những ván dăm hỗn hợp khi sử dụng tỷ lệ phối trộn giữa dăm vỏ Ca cao 30% với tỷ lệ keo từ 6% đã đạt được tiêu chuẩn TCVN 7754-2007 về cường độ uốn tĩnh (MOR), cường độ kéo vuông góc (IB). Điều kiện tối ưu khi sử dụng tỉ lệ phối trộn dăm vỏ Ca cao và dăm tre 30.6% với tỷ lệ keo UF 8.1% sẽ đạt được giá trị lớn nhất của MOR là 13.1 MPa và IB là 0.33 MPa và đạt giá trị thấp nhất của độ trương nở chiều dày (TS) ván là 13.2%.

Từ khóa: Đặc tính cơ lý, tre, ván dăm, vỏ quả Ca cao.

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