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Effect of Rice Straw Steaming Time and Mixing Ratio between *Acacia mangium Willd* Wood and Steamed Rice Straw on the Properties of the Mixed Particleboard

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Abstract

This study examined the effects of rice straw steaming time and mixing ratio between rice straw and wood particle on the properties of mixed particle board from *Acacia mangium Willd* wood and rice straw. Rice straw and *Acacia mangium* Willd wood were collected in Hanoi, Vietnam. The particle board was three-layer particle board with the structural ratio of 1 : 3 : 1. The thickness, density and board size of the particle board were 18 mm, 0.7 g/cm^3, and 800x800x18 (mm, including trimming), respectively. A resin mixture between commercial Urea-formaldehyde (U-F) adhesive and methylene diphenyl isocyanate (MDI) adhesive was used with a dosage of 12% for the core layer and 14% for the surface layer. In this experimental design, the steaming time for rice straw was 15, 30, 45, 60, and 75 minutes at 100°C. The rice straw-wood mixing ratio was 10, 20, 30, 40, and 50%. The results showed that both mixing ratio and steaming time affect the properties of the particleboard, but the mixing ratio has a stronger impact. A higher mixing ratio and a longer steaming time resulted in a better quality of particleboard. The optimal steaming time for rice straw was 46.12 minutes with the straw-wood mixing ratio of 29.85% with the following characteristics of the particle board: the modulus of rupture (MOR) of 14.64 MPa, internal bond strength (IB) of 0.382 MPa, thickness swelling (TS) of 8.83%, and board density of 0.7-0.73 g/cm^3.

Key Words: *Acacia mangium Willd* wood, internal bond strength (IB), mixed particle board, rice straw, steaming

Introduction

Wood based panel industry in the world in general and in Vietnam in particular has been quickly developing as one of the high value-added products. They are commonly used as building and furniture making materials, as well as in interior design. However, one of the difficulties for the industry is that the wood resource is becoming scarce due to the increasing reduction of natural and man-made forest areas. Therefore, to meet the increasing demand for wood based panels, we must either use wood materials more efficiently or seek new raw materials using a mixture of wood and wood wastes or agricultural residues such as saw dust, wood shavings, rice straw, rice husk, bagasse, peanut shell and jute fiber of which rice straw provides a promising alternative to wood materials and thus need to be paid more attention.

Vietnam is an agricultural country with a long history of

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paddy rice production. In 2013, the Vietnamese rice production was 44.1 million tons with an increase by 338.3 thousand tons and rice cultivation area was about 7.9 million ha with an increase of 138.7 thousand ha compared to that in 2012 (GSO 2014). The government of Vietnam has formulated different policies to promote paddy rice production, including agricultural land reform policy (Nguyen 2008; Nguyen 2012). During the rice harvesting season, a huge amount of rice straw are created (equivalent to 44 to 66 million tons of rice straw annually based on estimation by Binod et al. (2010)) and a large part of rice straw burn, leading to not only an environmental pollution problem but also a waste of this valuable raw material. The global experience has indicated that rice straw could be used to make particle boards for interior furniture and thus as a substitute for wood materials (Youngquist et al. 1993; Rowell 1998; Mantanis and Berns 2001; Cai and Winandy 2006; Binod et al. 2010). Regarding forest production, the forest cover of Vietnam was about 39.5% in 2010 (Nguyen et al. 2013) with a sharp increase compared to that of about 28% in 1995 (Nguyen et al. 2014). Therefore, the combination between rice straw and wood particle in a rice and forest based economy like Vietnam might open a new and optimistic way in the wood industry by utilizing this agricultural residue to diversify wood based products and solve the problem of wood raw material shortage.

There have been a number of studies on how to produce particle boards from mixing wood and straws (Mei and Zhou 2001; Mo et al. 2001; Yang et al. 2003; Saadatnia et al. 2008). Results of these studies show that the bondability of rice straw is poorer than that of wood; and mixing rice straw with wood could improve the particleboard properties. However, it is still unsure whether these results could be directly applicable to Vietnamese ecological conditions, especially with Vietnamese rice straw and its tropical hardwoods. In Vietnam, there have been some efforts on wooden particleboard technological development during the last 20 years (Thiet 1996; Chu 2001; Duong 2004; Duc 2005). These include using rice straw to produce particleboards by firstly treating rice-straw with some chemicals or steaming, then producing particleboard using U-F resin (Hung 2010; Ngoc 2010; Hien 2011). Although steaming or chemical treating could be possible to improve the bondability of rice straw with UF resin, but the particleboard properties are still not high, especially its mechanical properties. According to Wang et al. (2006), adding este isocyanate (MDI) into urea-formaldehyde resin (U-F) for making particleboard could significantly reduce the formaldehyde content (below 9 mg/100 g board, E1 type requirement) with a higher board strength. Therefore, in this study, we investigated the effects of rice straw softening treatment time by steaming and the mixing ratio between treated rice straw and wood particle for improving the quality of mixed particle boards from *Acacia mangium* wood and rice straw. Based on these results and we solved the multi-objective optimization problem to calculate the optimum mixing ratio and steaming time for better properties of the mixed particleboard. Our study is thus an important contribution to the development of the wood based panel industry in Vietnam.

Materials and Methods

Materials

Acacia mangium wood

Acacia mangium wood was collected from a forest stand of 9 years old in Bavi district of Hanoi, Vietnam. Its oven-dried density is 0.55 g/cm^3 and the air-dried density (at 12% moisture content) is 0.58 g/cm^3. The volumetric shrinkage is 6.7% and the volumetric shrinkage coefficient is 0.46. The mechanical properties of *Acacia mangium* planted in Bavi tested at 12% moisture content are as follows: modulus of rupture of 99 N/mm^2, modulus of elasticity of 10,000 N/mm^2, longitudinal compression strength of 43 N/mm^2, shear strength along the grain of 12.7 N/mm^2, split stress of 12.7 N/mm. The main chemical composition in the *Acacia mangium* is as follows: holocelullose (78%), α-celullose (46.5%), lignin (27%), pentozan (14%) and ash (0.2%); extractives in alcohol-benzen (3.8%), in hot water (3.3%), and in NaOH (13.4%).

Rice straw

The rice straw used in this study was from two rice varieties, namely Q5 and Hai dong (hybrid) collected in Chuong My district, Hanoi. The main chemical composition of the rice straw (based on oven-dried weight) is as follows: wax (3.72%), hemicellulose (35.50%), cellulose (39.63%), lignin (13.92%), ash (12.51-18%), silic (9.68%), other minerals (Na, K, Ca, P, Fe) (6.03%), sugar composition (1.25%).

With a high ash content and hydrophobic layer of wax on the surface of the stem, rice straw particle has poor wettability which affects its bondability and reduces the physical and mechanical properties of the particleboard. Additionally, rice straw has a lower lignin content and higher extractives in both hot and cold water comparing to wood.

Adhesive

This study used Dynea U-F (Dynchem WG -2888) and MDI (Casco adhesive) with a mixing ratio of U-F:MDI= 5 : 1. The resin dosage was 14% for surface layer and 12% for core layer. The hardener is NH_4Cl with 1% in weight compared to the resin.

The specification of U-F glue was tested and the result is as follows: liquid form with white color, solid content of 47%, density of 1.25-1.27 g/ml, viscosity (measured by Rion Viscoteter VT-04, according to standard GB/T 14074.7-93) of 100-180 mPa.s (at 30°C); pH of 7.0-7.2 (tested at 20°C); gel-time of 67 s (at 100°C), free formaldehyde content of less than 0.5%, storage time of 2 months at 30°C.

The specification of the MDI was tested and the result is as follows: liquid form with brown color, solid content of 49%, density of 1.26-1.29 g/ml, viscosity (measured by Rion Viscoteter VT-04, according to standard GB/T 14074.7-93) of 300 mPa.s (at 30°C), pH of 7.1-7.4 (tested at 20°C); gel-time of 69 s (at 100°C), free formaldehyde content of less than 0.4%; storage time of 2 months at 30°C.

The specification of the mixture of U-F and MDI glue was tested and the result is as follows: liquid form with brown yellow color, solid content of 49%, density of 1.25-1.28 g/ml, viscosity (measured by Rion Viscoteter VT-04, according to standard GB/T 14074.7-93) of 200 mPa.s (at 30°C), pH of 7.0-7.3 (tested at 20°C), gel-time of 68 s (at 100°C), free formaldehyde content of less than 0.5%, storage time of 2 months at 30°C.

These test results, therefore, show that the mixture of UF-MDI might be possible for making particleboard.

Wax

Based on the previous studies of Hung (2010), Ngoc (2010), Hien (2011), this study used the parafin solution made by Guangdong Chemical Company, China with the following properties: colorless, insoluble in water, alcohol or glue, soluble in ether and CCl_4, density of 0.835-0.855 g/cm^3, concentration of 60-65%, melting point of 60°C, thermal degradation temperature of 170°C, burning temperature of 360°C, and the paraffin dosage used for particleboard of 1%.

Experimental methods

Expected properties of particleboard

Based on the above described characteristics of the materials and the requirements for interior furniture making, the following particle board was made. The experimental design followed Bi (2005).

A 3-layer particleboard with a structural ratio of 1 : 3 : 1 would be produced using BYD 113 hot press. The mixing ratios based on weight basis of rice straw/*Acacia mangium* wood particle are 10 : 90, 20 : 80, 30 : 70, 40 : 60, 50 : 50. The thickness of particleboard is 18 mm with a density of 0.7g/cm^3; The dimension of particleboard (including trimming) is 800x800x18 (mm). The moisture content of the face layer mat is 15-18%, while that of the core layer mat is 10-12%.

The requirements for particleboard using in furniture making and building materials (Type 2) are as follows (according to the Vietnam National Standards TCVN 7754-2007):

Modulus of rupture (σ_u) ≥ 14 MPa

Internal bond strength (σ_k) ≥ 0.35 MPa

Thickness swelling (TS) ≤ 12%.

Mathematic model

Based on the experimental conditions, we selected the multi-factor experimental design (quadratic regression model) with two factors (steaming time and mixing ratio) and three replications, the number of experiments (M) could be calculated as follows (Bi 2005):

$$M = k\,(2n + 2^n + 1)$$

Where M - number of experiments; k - replication number (k=3); n - number of factors (n=2). Therefore, M=27.

The factors of the experimental design: steaming time of rice straw at 100°C (τ), the mixing ratio of rice straw/wood particle (K). The experiment level and value of each factor at the respective level are described in Table 1.

The particleboard production scheme

The technological procedure of making particleboard mixed from *Acacia mangium* wood and rice straw is described in Fig. 1 as follows.

Acacia mangium wood harvested in Ba Vi was quickly debarked, cross-cut and then chipped to prevent from mould growth using a BX444 chipper at the Wood Processing Lab of the Vietnam Forestry University. The wood particles were screened to remove over-size particles and seperated into two types: core and face particles. These particles were then dried using a rotary drier to 3-5% for the core layer and 4-6% for the face layer. The dimension of the *Acacia mangium* particles was as follows:

Face layer particles: white with 0.20-0.25 mm in thickness and 10 mm in length (length to thickness ratio of about 50).

Core layer particles: white with 0.35-0.45 mm in thickness or thicker and 25 mm in length (length to thickness ratio of about 40-50).

The rice straw collected from Chuong My district was short-cut to a 20 cm length after drying under sun shine (about 15% moisture content). The straw was grinded and screened to the face particle and core particle using screen mesh diameters of 10, 5, 2.5, 1.25, 0.63 and 0.375 mm. The recovery rate was 60%. The rice straw was then pre-treated by steamming time of 15, 30, 45, 60 and 75 minutes, respectively.

The *Acacia mangium* particles and treated rice straw particles were mixed with the following mixing ratio in weight: 10; 20; 30; 40; 50. The UF and MDI were mixed, and then added parrafin to make homogeneous solution. Glue was sprayed on the particles using a rotary blender. The dosage for face layer was 14% (w/w) and for core layer was 12% (w/w). The pH of glue for the face layer and the core layer was 6.5 and 5.5, respcetively.

The mat forming was done manually. The mat was pre-pressed by handy tools. The particleboard structure ratio was 1 : 3 : 1 (face-core-back) in thickness. The BYD 113 hot press was used for making particleboard. The pressing conditions weree as follow: pressing temperature of 160°C, pressing time of 0.6 minute/mm thickness of the board

Table 1. Experiment level and factor value in experiment design

Factors		Experiment level				
Factor name	Code	$-\alpha$	$-$	0	$+$	$+\alpha$
Mixing ratio of rice straw/wood particle	K (%)	10 (10 : 90)	20 (20 : 80)	30 (30 : 70)	40 (40 : 60)	50 (50 : 50)
Steaming time	τ (minutes)	15	30	45	60	75

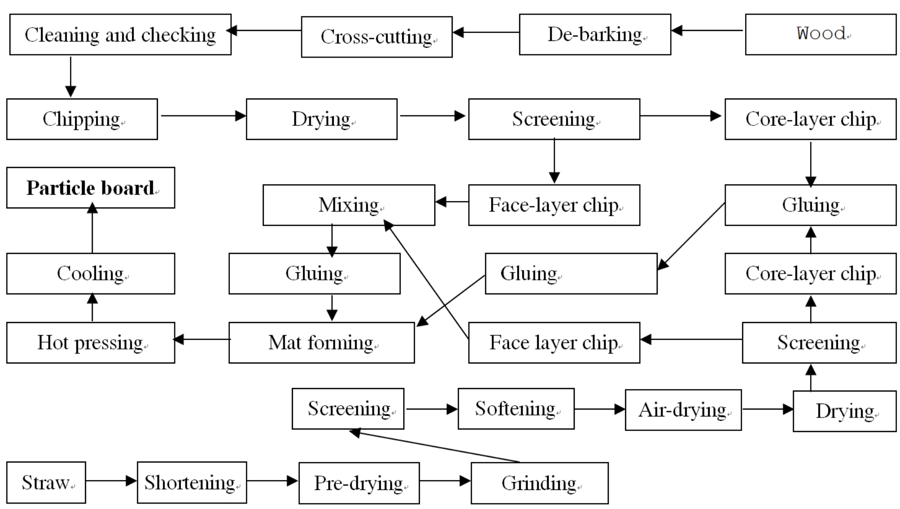

Fig. 1. Particle board production scheme.

(equivelant to 10.8 minutes), and maximum pressure of 2.5 MPa. After hot pressing, particleboards were cooled down, and then conditioned in a climate chamber at an environment of 27°C (temperature) and 65% (relative humidity) for 48 hours. This procedure resulted in the moisture content of the particleboards of 12%.

Testing particleboard

The particle boards were then cut into specimens to test their properties. The board density (γ) was tested using the Vietnam National Standard TCVN 7756-4: 2007. The thickness swelling (TS) was tested using the Vietnam National Standard TCVN 7756-5: 2007. The bending strength (MOR) and internal bond strength (IB) were tested using testing machine MTS-QTest/25 at the Lab of the Wood Technology Institute, Vietnam Forestry University using the Vietnam National Standard TCVN 7756-7: 2007 and 7756-6:2007.

Results and Discussion

Experimental results

The input parameters and properties of the mixed particleboards produced from the steamed rice straw and *Acacia mangium* wood are shown in Table 2.

The correlation equations for the relationship between the mixing ratio of rice straw/wood particle, steaming time of rice straw and some properties of the particleboards (thickness swelling, modulus of rupture, internal bond strength) are as follows:

$$TS=11.823-0.282K+0.0231K^2-0.734\tau-0.045K.\tau-0.38\tau^2$$

$$MOR=-13.78+7.845K-0.261K^2+3.546\tau-0.56K.\tau+0.491\tau^2$$

$$IB=-12.63+0.291K-0.35K^2+2.842\tau-0.73\tau.K+0.21\tau^2$$

The significance of the coefficients in these equations was checked with the Student T test. The mathematical models were significant with the significant Fisher test. The homogeneity of the variance was checked with the Kohren test.

Table 2. Input parameters and properties of the mixed particleboard (mean values)

N_0	Input parameters		Properties of the particleboard			
	K (%)	τ (mins)	TS (%)	γ (g/cm^3)	MOR (MPa)	IB (MPa)
1	40	60	14.13	0.705	13.89	0.321
2	20	60	13.23	0.689	15.11	0.315
3	40	30	14.18	0.713	14.98	0.346
4	20	30	12.98	0.735	13.65	0.352
5	50	45	11.75	0.675	14.21	0.378
6	10	45	12.23	0.723	14.76	0.354
7	30	75	10.45	0.716	14.02	0.383
8	30	15	12.38	0.689	13.18	0.378
9	30	45	11.23	0.713	15.12	0.364
10	Control		9.21	0.723	16.73	0.391

Based on the results in Table 2 and the regression anaysis, the findings are as follows

The particle board density in different treatment times and mixing ratios does not varry and reach an average value of 0.7g/cm^3;

With regard to the effect of the mixing ratios:

The thickness swelling of the control particleboard (no rice straw) is lower than the mixed particleboard from *Acacia mangium* wood and rice straw. Additionally, the internal bond strength of the control is also higher than that of the mixed particleboard;

The thickness swelling slightly reduces when the mixing ratio increases from 10% to 20%. However, the thickness swelling increases when the mixing ratio continously increases over 20% (rice straw amount increase). The internal bond strength and modulus of rupture decrease when the mixing ratio increases from 10% to 20% and decreases even quicker when the mixing ratio increases over 20%.

With regard to the effect of softening treatment (steaming) time:

When the treatment time increases from 15 minutes to 45 minutes, the thickness swelling of the mixed partcileboard drastically decreases; but the internal bond strength and modulus of rupture increase. However, when the treatment time is longer than 45 minutes, the thickness swelling increases but the internal bond strength and modulus of rupture decrease.

The coefficients in the regression equations shows that the coefficient of the mixing ratio (K) is higher than the coefficient of the treatment time (τ). This shows that the mixing ratio between *Acacia mangium* and rice straw has a stronger effect than that of the softening treatment time of rice straw.

These effects could be explained as follows

Rice straw is porous/ cellular structure material. It can absorb moisture. In rice straw, there is high amount of silic, wax and sugar (silic of 9.68%, sugar of 1.25%, wax of 3.72). These substances obstact the bondability of glue. Therefore, we have to soften rice straw to remove/change the structure and content of these substances by chemicals such as H_2O_2 and/or NaOH as shown in Mo et al (2001) or steaming as shown in Han et al. (2010), Li et al. (2011). However, the chemicals are expensive and require complicated equipments which increase the cost of making particleboard. Steaming is, therefore, an alternative with a lower cost and a more environmental friendly option.

When the mixing ratio increases from 10% to 20%, rice straw acts as a filler to fill in the "gap" and create "bridge" to link particles together. That's why the thickness swelling decreases and the internal bond strength and modulus of rupture increase. However, when the ratio increases more than 20%, the particleboard properties decrease because rice straw itself with a poor bondability and lower lignin content would decrease all properties of the mixed particleboard.

Determining the optimum condition

To determine the optimum conditions (treatment time and mixing ratio), we considered the quality requirement of particleboard for making interior furniture as type 2 as the target (minimum requirement). From the established regression equations described above, we solved the optimum problem by the extra value exchange method proposed by Haimes et al. 1971. The optimum conditions was identified as follow: the steaming time is 46.12 minutes, the mixing ratio of rice straw/*Acacia mangium* wood particle is 29.85%. The quality of mixed particleboard can then be obtained as follow: modulus of rupture (MOR): 14.64 MPa, internal bond strength (IB) 0.382 MPa, thickness swelling (TS): 8.83%, board density 0.7-0.73 g/cm^3.

Conclusions

The rice straw steaming time and the mixing ratio between wood particle and rice straw both affect the properties of the mixed particleboard, but the mixing ratio has a stronger effect than the steaming time. The higher mixing ratio, the poorer properties of mixed particleboard.

The optimum conditions for producing mixed particleboard from *Acacia mangium* wood particle and steamed rice straw are as follow: steaming time is 46.12 minutes, mixing ratio is 29.85%. The properties of the particleboard could be obtained: modulus of rupture of 14.64 MPa, internal bond strength of 0.382 MPa, thickness swelling of 8.83% with board density of 0.7-0.73 g/cm^3.

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