

COMPATIBILITY OF SOME ADHESIVES WITH BATANG RATTAN (*Calamus zollingeri* Becc.) AS RAW MATERIAL OF RATTAN LAMINATED BOARD

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COMPATIBILITY OF SOME ADHESIVES WITH BATANG RATTAN (*Calamus zollingeri* Becc.) AS RAW MATERIAL OF RATTAN LAMINATED BOARD. Rattan in Indonesia is traditionally utilized for furniture, binding materials, household appliances, and handicraft items. Small diameter rattans are commonly used by craftsmen, while large diameter rattans are not optimally utilized. Large diameter rattan, however, has potential to be developed into rattan laminated board (RLB) by gluing rattan strips using appropriate adhesive. Nevertheless, the information of the suitable natural adhesive for RLB production is still limited. Laboratory scale of RLBs with the dimensions of 60 cm x 7.5 cm x 1.5 cm were manufactured using batang rattan strips (*Calamus zollingeri* Becc.). The strips were glued with six types of adhesives (4 types of natural adhesives and 2 types of commercial synthetic adhesives) and three glue spread rates of (100, 150, and 200 g/m²) were used. The study objective was to determine the effect of rattan pre-treatments, adhesive types and glue spread rates on the bonding quality and formaldehyde emission of RLBs. The results showed that batang rattan can be processed into RLBs by using natural adhesives originating from wood bark extract (mangium, mahogany), merbau wood powder, as well as commercial synthetic adhesives such as isocyanate and polyurethane. The appropriate pre-treatment in producing RLBs for interior furniture was by applying oil heat treatment with kerosene solution (80 kerosene : 20 water) and glued with tannin adhesive of mangium bark extract with glue spread of 200 g/m². Similarly, rattan strips treated with heated oil (80 kerosene : 20 water) and glued with polyurethane adhesive (glue spread of 200 g/m²) produced excellent RLBs for exterior furniture.

Keywords: *Calamus zollingeri* Becc., bonding strength, formaldehyde emission, rattan laminated board, natural adhesives

KESESUAIAN BEBERAPA JENIS PEREKAT DENGAN ROTAN BATANG (*Calamus zollingeri* Becc.) SEBAGAI BAHAN BAKU PAPAN ROTAN LAMINASI. Di Indonesia, rotan secara tradisional digunakan untuk furnitur, tali pengikat, alat rumah tangga, dan barang kerajinan. Rotan yang digunakan oleh pengrajin, pada umumnya adalah rotan berdiameter kecil, sedangkan rotan berdiameter besar kurang digunakan secara optimal. Namun demikian, rotan diameter besar berpotensi untuk dikembangkan menjadi papan rotan laminasi dengan merekatkan bilah rotan menggunakan perekat yang sesuai. Akan tetapi, informasi kesesuaian perekat alami untuk pembuatan papan rotan laminasi masih sangat terbatas. Papan rotan laminasi skala laboratorium dengan dimensi 60 cm x 7,5 cm x 1,5 cm dibuat dari bilah rotan batang (*Calamus zollingeri* Becc.). Bilah rotan direkat dengan menggunakan 6 macam perekat (4 macam perekat alami dan 2 macam perekat sintesis komersial) dan tiga macam berat labur (100, 150, dan 200 g/m²). Tujuan penelitian ini adalah untuk mengetahui pengaruh pra-perlakuan, macam perekat, dan berat labur terhadap keteguhan rekat dan emisi formaldehida papan rotan laminasi. Hasil penelitian menunjukkan bahwa rotan batang dapat dibuat menjadi papan rotan laminasi dengan menggunakan perekat alami yang berasal dari ekstrak kulit kayu (mangium, mahoni), ekstrak serbuk gergajian kayu merbau, dan perekat sintesis komersial seperti isosianat dan poliuretan. Pra-perlakuan yang sesuai untuk membuat papan rotan laminasi sebagai bahan furnitur interior adalah perendaman rotan dalam larutan minyak tanah panas (80 minyak tanah : 20 air) dan direkat menggunakan perekat tanin dari ekstrak kulit kayu mangium dengan berat labur 200 g/m². Sementara itu, pra-perlakuan dengan perendaman rotan dalam larutan minyak tanah panas (80 minyak tanah : 20 air) dan direkat menggunakan perekat poliuretan (berat labur 200 g/m²) menghasilkan papan rotan laminasi yang sangat bagus untuk mebel di luar ruangan.

Kata kunci: *Calamus zollingeri* Becc., keteguhan rekat, emisi formaldehida, papan rotan laminasi, perekat alami

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I. INTRODUCTION

Rattan is a multipurpose monocotyledonous plant with a long, hard slender stem, commonly found in tropical rain forests (Akpenpuun, Adeniran, & Okanlawon, 2017). It is considered an important forest product after wood and bamboo. It is widely used as an excellent natural material for furniture, ropes, decorative items, housing, handicraft products, and also as an innovative bone implant material (Adefisan, 2011; Eichenseer et al., 2010; Olorunnisola & Adefisan, 2002). Rattan is one of the original biological natural resources from Indonesia which has very significant economic value for the country's income, because Indonesia supply 80% of all the world's rattan needs, with producing areas spread across various islands, especially in Kalimantan, Sulawesi and Sumatera. Data from the Ministry of Industry showed that in 2019 the value of national furniture exports reached US\$1.69 billion (Rp. 23.66 trillion) (Ministry of Industry, 2019).

Rattan has elastic and flexible properties to be processed into several furniture products and has several advantages compared to wood such as light weight, strong, and cheap (Pujiati, 2017). Moreover, Ahmad et al. (2019) mentioned that rattan's great versatility, such as its durability, elasticity, light-weight, shiny and flexibility can be used in furniture industries, construction materials, household articles, tool handles, and lifting heavy items and bridge construction. Furthermore rattan as natural fibers can be used as an advanced polymer composite material for various applications (Sahoo et al., 2019), and the strength properties are related to cellulose and lignin content (Munshi et al., 2020). Rattan chemical composition consists of holocellulose (71-76%), cellulose (39-60%), lignin (18-48%), silica (0.54-8.0%), and starch (14-29%) (Rachman & Jasni, 2013). Rattan can also be used as cement-bonded rattan composites (Olorunnisola & Agrawal, 2015, 2018; Olorunnisola & Asimiyu, 2016).

Rattan utilization in Indonesia is traditionally for furniture, furniture frame from

round rattan, binding materials for traditional house components, household appliances, and handicraft items. The raw materials used by craftsmen are commonly rattan with a small diameter of < 20 mm, while rattan with large diameter of >20 mm are not optimally utilized, resulting in an increasing amount of waste in the form of discarded rattan poles. Nevertheless rattan with large diameter can further developed into composite products in the form of Rattan Laminated Board (RLB) with the desired dimensions from rattan strips with the aid of appropriate adhesives. Studies on the manufacture of rattan laminated boards have been done by using water based polymer-isocyanate (WBPI) adhesive (Sulastiningsih, Trisatya, & Sukadaryati, 2019) and by using tannin-based adhesive (Pari, Abdurachman, & Santoso, 2019; Santoso & Pari, 2020). Studies on the pre-treatment of raw materials for the application of rattan laminate boards have not been widely carried out.

The round-shaped rattan has must be converted into strips and glued with a suitable adhesive to be fabricated as rattan laminated board (RLB). Constraints faced in the manufacturing of good quality rattan laminated board, among others is that there is not enough information regarding the type of natural adhesive suitable for the production of RLB. Therefore a research was carried out with the objective to determine the compatibility of six types of adhesives (4 types of natural adhesives (tannin-based adhesive) and 2 types of commercial synthetic adhesives with rattan batang strips as raw material for rattan laminated board. The evaluation was conducted by testing the bonding strength and formaldehyde emission of RLBs.

II. MATERIAL AND METHOD

A. Materials

The batang rattans (*Calamus zollingeri* Becc.) used in this study were 2 meters in length with diameters ranging from 27.91 to 34.53 mm with

an average of 29.47 mm, densities ranging from 0.49 to 0.58 g/cm³ with an average of 0.55 g/cm³ collected from Ampibabo Subdistrict of Prigi Moutong Regency (Central Sulawesi). Other materials used in this study were preservatives, tannin formaldehyde, tannins from bark extract and sawdust powder and commercial synthetic adhesives.

B. Methods

1. Chemical Component Analysis of Rattan Cane

The chemical components of rattan cane were measured using pyrolysis gas chromatography mass spectrometry (py-GCMS-QPXP-2010; Shimadzu). The analysis was carried out on a fused silica capillary column (HP-SMS column, 60 m by 0.25 mm with a film thickness of 0.25 µm; Agilent). About 1 µg of rattan cane powder was inserted without any further preparation into the bore of the pyrolysis solids injector and then placed with the plunger on quartz wool in the quartz tube of the furnace pyrolyzer Pyrojector II (S.G.E., Melbourne, Australia) with a constant temperature of 400°C and a total run time of 50 minutes. The pressure of the helium carrier gas at the inlet to the furnace was 101 kPa. The pyrolyzer was connected to a 7890A gas chromatograph with series 5975C quadropole mass spectrometer operated in electron impact ionization mode.

2. Adhesive Preparation

The procedure for preparing the tannin resorcinol formaldehyde (TRF) adhesive made of tannin from mangium and mahogany bark extract refers to Santoso, Hadi and Malik (2012), and Lestari et al. (2015). A similar procedure was applied to the TRF adhesive made of merbau sawdust extract (Hendrik et al., 2019; Malik et al., 2016; Santoso et al., 2016a; Santoso et al., 2012). While the procedure of preparing tannin formaldehyde (TF) adhesive refers to Hendrik et al. (2018). A phenolic compound in tannin was activated by resorcinol addition. This study used two types of commercial adhesives were used, namely isocyanate and polyurethane as a comparison.

3. Preparation and Manufacture of Rattan Laminated Boards

Rattan canes were pre-treated by immersing in 2 different heated kerosene solutions (A1 solution in which 80 parts of kerosene was mixed with 20 parts of water and A2 solution in which 70 parts of kerosene was mixed with 30 part of water). Immersion was done for approximately 20 minutes. The purpose of pre-treatment was to remove dirt and resin from the surface of rattan skin, thus speeding up the drying process. Rattan canes were then sun-dried to about 15% moisture content and the cane's outer layer removed. The rattan cores were then manually fed into the rattan splitter machine to produce rattan strips with the dimension of 1.5 cm x 1.5 cm x 200 cm. The rattan strips were immersed in 7% w/v boron solution at room temperature for 2 hours and then sun-dried to about 12% moisture content. The rattan strips were sorted for straight and uniform dimensions and then were cross-cut to 60 cm in length and were used to produce rattan laminated boards.

Laboratory scale of rattan laminated boards (RLBs) with the dimension of 60 cm x 7.5 cm x 1.5 cm were manufactured by assembling 5 rattan strips, which were horizontally arranged side-by-side and glued with six types of adhesives (Mb (C1) = tannin resorcinol formaldehyde (TRF) adhesive made of tannin from merbau wood extract, Ac (C2) = TRF adhesive made of tannin from mangium bark extract, Mh (C3) = TRF adhesive made of tannin from mahogany bark extract, TF (C4) = tannin formaldehyde adhesive made of tannin from mangium bark extract without resorcinol, ICN (C5) = isocyanate adhesive, PU (C6) = polyurethane adhesive) and in combination with three various glue spreads of 100 g/m² (B1), 150 g/m² (B2), and 200 g/m² (B3). The rattan strips assemblies were cold pressed using wooden clamps for three hours. Four replications for each treatment combination were prepared. The RLBs produced were conditioned at room temperature for one week before testing.

4. Evaluation of Rattan Laminated Boards

The characteristics evaluation of each type of adhesive was carried out regarding JIS K 6833-1994 (JIS, 1994) and SNI (1998), consisting of organoleptic test, pH, viscosity, specific gravity, solid content, and free formaldehyde. The imported phenol resorcinol formaldehyde (PRF) was used as a comparison (Akzonobel, 2001). The properties of rattan laminated boards comprised of moisture content, density, formaldehyde emission and bonding strength were tested according with Japanese standards (JAS, 2003), and Indonesian standards (SNI, 2005). The bonding strength of RLB samples from the National Rattan Innovation Center (PIRNAS) was also tested as a comparison.

A. Data Analysis

A completely randomized design with factorial experiment was used in which the treatment factor A as the pre-treatment process (using oil and water mixture with a volume ratio of 80:20 and 70:30), various glue spread as the treatment factor B (100, 150 and 200 g/m² on the surface), and six types of adhesives as the treatment factor C (4 types of tannin adhesives, 2 types of synthetic adhesives). Four replications were prepared for each treatment combination.

III. RESULT AND DISCUSSION

A. Chemical Components of Rattan Cane

The results of the analysis with py-GCMS (Figure 1) show that the chemical components in rattan cane are dominated by phenolic group compounds (37.86%), such as Guaiacol, 2-Methoxy-4-methyl phenol; class of sugar (15.75%), such as alpha-L-Galactopyranoside; amine groups (6.67%) such as cis-1,3-Dideuterio-1,3-cyclohexan diamine, N-Hydroxy Acetaminophen, 2,6-Dimethoxyphenol; carboxylic acid groups (4.92%), such as Stearic acid, 9,12-Octadecadienoic acid, Oleic acid, and Elcosa-5,8,11,14-Tetraynoic acid; group of ketones (4.79), such as 4,7-Methano-1H-indene-1,8-dione, Ethanone, 6,7-Dihydro-3-nitro-5H-Cyclo-penta [B] Pyrin-2 (1H)-one.

The presence of sugar groups and carboxylic acids in rattan stems, which are hygroscopic and easily hydrolyzed in water (both cold and hot), will dissolve the adhesive that is applied to the surface of the rattan so that the adhesive is diluted, it will also result in thinner adhesive lines and the glued products will be delaminated during immersion test in cold water (interior test) or boiling water (exterior test). As a result, the bonding strength value of laminated rattan products will be very low, even delaminated.

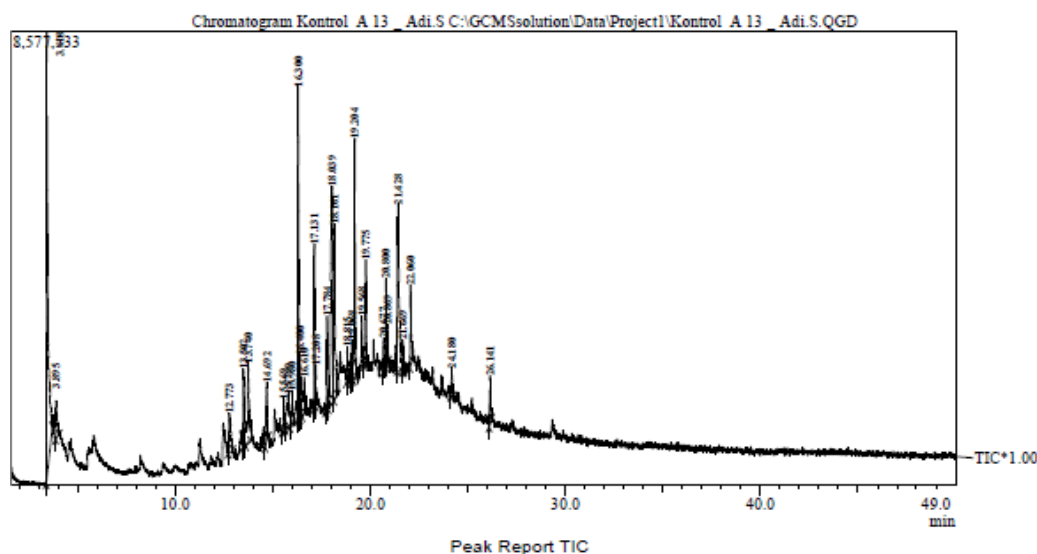


Figure 1. Chromatograph of chemical component of rattan *Calamus zollingeri* Becc.

On the other hand, the results of extractive substances analysis (Figure 2) in rattan cane showed that non-polar compounds of alkane groups (24.41%), such as n-Tridecane, n-Pentadecane, n-Hexadecane, n-Heptadecane; polar bit ketone compound (23.21%), such as 2-Hepta-decanone, Palmitone; polar group carboxylic acid compounds (40.65%), such as Methyl palmitate, Palmitic acid, Methyl stearate, 9-Hexa-decenoic acid, Stearic acid. The existence of extractive substances especially from the nonpolar group will inhibit the interaction of adhesive with adherend, so the chemical bond between the two materials is not maximum, consequently the bonding strength of the rattan laminated product will be low (Pizzi, 1983).

B. Characterization of the Physical-Chemical Properties of Adhesives

The characteristics of each type of adhesive used to produce rattan laminated boards (RLBs) are presented in Table 1.

Characteristics of phenolic group adhesives synthesized from biological raw materials such as merbau, mangium, and mahogany bark extracts have relatively similar properties to each other. Still, they are different from imported commercial synthesis (isocyanate and polyurethane) adhesives commonly used in the wood processing industry. The difference

is very obvious especially in solid content and gelatinous time. In practice, adhesives that have high solid content will have high adhesive properties, while the shorter gelatinous time will be detrimental in terms of application of the adhesive because it will have a short pot life, so the material has been spread by adhesive if not immediately assembled will overheat and dry too quickly, as a result of the adhesive penetration into the adherend material is minimal, so the bonding quality of the product will be low.

According to Maloney (1977), a high density resin with a corresponding viscosity will enable it to penetrate the wood pores properly and form an optimum bond, resulting in a satisfactory adhesion. One of the fundamental properties of the adhesive in bond formation is viscosity. The higher the viscosity the shorter the pot life of the adhesive. It will harden faster than the low viscosity, so the quality of the adhesive is relatively low. According to Pizzi (1983), the minimum recommended pot life of adhesive \pm 88 minutes. On the other hand, Vick (1999) suggested that the maximum adhesive bonds can be achieved if the adhesive soaks all the adherent surfaces so that contact between the adhesive molecule and the wood molecule occurs, thereby intermolecular attraction between the wood and the adhesive can be

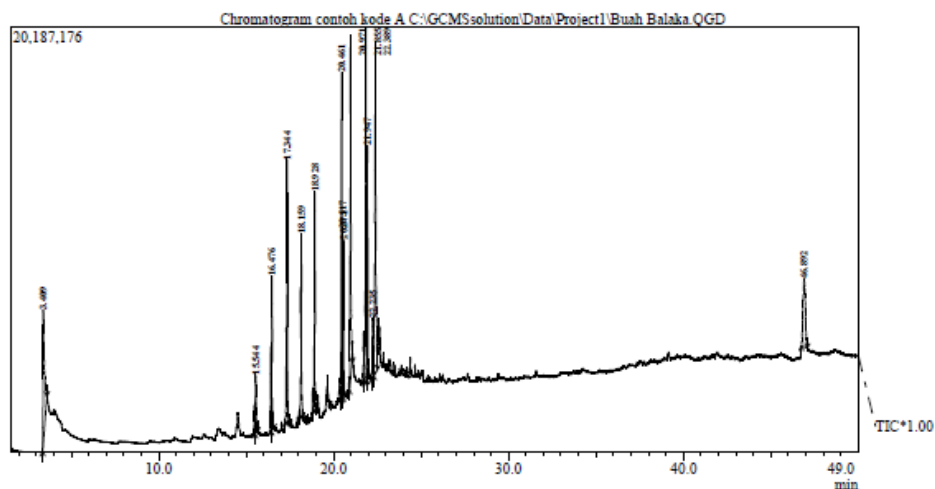


Figure 2. Chromatograph of the extractives of the chemical component of rattan *Calamus zollingeri* Becc.

Table 1. Characteristics of the adhesive types used for the manufacture of RLBs^{*)}

Properties	Adhesive types					
	Mb (C1)	Ac (C2)	Mh (C3)	TF (C4) **	ICN (C5)	PU (C6)
Visual test:	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
• Phase	Dark red	Dark red	Dark red	Dark red	Dark red	Dark red
• Color	Phenol	Phenol	Phenol	Phenol	Phenol	Phenol
• Odor						
pH	10.50	9.99	10.00	10.50	-	-
Viscosity, cp	8.67	7.16	11.35	12.34	-	-
Specific gravity	1.06	1.06	1.07	1.02	-	1.14
Solid content, %	11.94	12.92	13.05	8.63	73.52	91.46
Free formaldehyde, %	0.004	0.003	0.004	0.054	-	-
Gelatinous time, minutes	110	180	160	300	15	30

Remarks: ^{?)} = Means of 3 replicates, Mb = tannin resorcinol formaldehyde (TRF) adhesive made of tannin from merbau wood extract, Ac = TRF adhesive made of tannin from mangium bark extract, Mh = TRF adhesive made of tannin from mahogany bark extract, TF = tannin formaldehyde adhesive made of tannin from mangium bark extract without resorcinol, ICN = isocyanate adhesive, PU = polyurethane adhesive, (-) = no data, ^{*)} Santoso & Pari (2020)

more fully bonded. Thus, the increase in solid resin content tends to improve the quality of the adhesive.

Free formaldehyde levels describe the presence of a formaldehyde excess in the formation of a polymer (SNI, 1998). This determination is undertaken to know the excess amount of unreacted formaldehyde in the adhesive formation, and the possible emission levels as a result of the formaldehyde being released. The test results show that the free formaldehyde of the adhesive used is entirely within safe limits for less than 3% as required for adhesives containing formaldehyde (SNI, 1998).

C. Evaluation of the Quality of Rattan Laminated Boards

The engineered rattan product made in this study was in the form of a 3-inch rattan laminated board measuring 60 cm x 7.5 cm x 1.5 cm in length, width, and thickness, respectively, using 4 types of synthesized adhesive types of natural resources and 2 types of commercial synthetic adhesives, while on

a pilot scale at PIRNAS the rattan laminated panel has the dimension measuring 400 cm x 60 cm x 6 cm, and produced using a commercial synthetic adhesive type from the resorcinol group commonly used in the wood processing industry (Pari et al., 2019). In this research we applied 3 kinds of glue spread rates on the surface, namely 150, 200, and 250 g/m². The test of bonding strength of adhesive by means of compressive shear strength was performed to determine the performance of the adhesive in the resulting rattan laminated boards (RLBs). The quality of the RLBs tested in the laboratory are presented in Table 2, which includes moisture content, density, bonding strength, and formaldehyde emissions.

The physical properties of RLBs, as one of the lignocellulosic-based products, are closely related to the nature of its strength. Yap (1984) stated that moisture content affects the strength and adhesion of lamina products. The rattan laminated boards produced in this study have an equivalent density (0.26–0.38 g/cm³) to the density of glued laminated timber made from sengon (*Falcataria moluccana* Miq.) and jabon

(*Anthocephalus cadamba* Roxb.) (0.25–0.37 g/cm³) glued with mahogany tannin based adhesive (Lestari et al. , 2018). The moisture content of RLB ranged from 9.46% to 10.63% which meets the JAS 234-2003 standard requirement since the moisture content of RLBs were less than 15%.

The results of the bonding strength in the wet condition of RLBs that were glued with natural adhesive has delamination of 100% so it could not be tested for its bonding strength, bonding strength of RLBs produced using commercial adhesives ranged from 2.28 kg/cm² to 26.33 kg/cm² (Table 2). The average bonding

Table 2. The average value of physical-mechanical properties and formaldehyde emission of RLBs

Pre-treatment method (A)	Adhesive type (C)	Glue spread (g/m ² surface) (B)	Parameters				
			Moisture content (%)	Density (g/cm ³)	Bonding strength (kg/cm ²)		Formaldehyde emissions (mg/L)
					Dry test	Wet test	
Mixture of kerosene with water 80:20 (A1)	TRF Mb (C1)	100	9.46	0.35	36.66	0.00	0.035
		150	10.03	0.37	41.49	0.00	0.044
		200	10.28	0.36	37.19	0.00	0.066
	TRF Ac (C2)	100	9.74	0.27	31.30	0.00	0.027
		150	10.11	0.33	44.39	0.00	0.034
		200	10.32	0.32	33.68	0.00	0.046
	TRF Mh (C3)	100	10.10	0.26	27.81	0.00	0.022
		150	10.21	0.29	35.61	0.00	0.023
		200	10.63	0.30	22.58	0.00	0.045
	TF Ac (C4)	100	10.33	0.30	39.47	0.00	0.545
		150	10.33	0.32	46.16	0.00	0.781
		200	10.34	0.33	34.77	0.00	1.212
	ICN (C5)	100	9.69	0.35	30.65	9.52	0.000
		150	10.17	0.37	37.64	9.79	0.000
		200	10.19	0.37	41.46	4.42	0.000
	PU (C6)	100	9.87	0.36	27.72	17.71	0.000
		150	10.04	0.37	33.52	25.66	0.000
		200	10.13	0.37	37.69	20.56	0.000
Mixture of kerosene with water 70:30 (A2)	TRF Mb (C1)	100	9.89	0.27	29.53	0.00	0.044
		150	10.04	0.29	32.56	0.00	0.057
		200	10.16	0.30	24.59	0.00	0.064
	TRF Ac (C2)	100	10.12	0.30	34.70	0.00	0.247
		150	10.15	0.32	45.38	0.00	0.277
		200	10.15	0.31	28.90	0.00	0.327
	TRF Mh (C3)	100	10.31	0.26	25.39	0.00	0.034
		150	10.33	0.29	37.50	0.00	0.038
		200	10.33	0.30	24.52	0.00	0.074
	TF AC (C4)	100	10.23	0.31	38.64	0.00	0.775
		150	10.31	0.33	41.55	0.00	2.042
		200	10.32	0.33	41.28	0.00	3.216
	ICN (C5)	100	9.29	0.35	29.66	18.67	0.000
		150	10.12	0.36	31.72	4.33	0.000
		200	10.16	0.38	41.58	2.28	0.000
	PU (C6)	100	9.89	0.36	44.71	20.60	0.000
		150	10.20	0.38	42.60	26.33	0.000
		200	10.23	0.38	37.70	20.52	0.000

Remarks: A1 = a mixture of kerosene with water 80:20, A2 = a mixture of kerosene with water 70:30, TRF Mb = tannin resorcinol formaldehyde (TRF) adhesive made of tannin from merbau wood extract, TRF Ac = TRF adhesive made of tannin from mangium bark extract, TRF Mh = TRF adhesive made of tannin from mahogany bark extract, TF = tannin formaldehyde adhesive made of tannin from mangium bark extract without resorcinol, ICN = isocyanate adhesive, PU = polyurethane adhesive.

strength of the RLBs made in the pilot scale at PIRNAS was 8.70 kg/cm². The low value of RLBs bonding strength which is tested in wet condition (for exterior condition) is likely caused by high levels of polar chemical components contained in rattan material, which is easily hydrolyzed in both hot and cold water, such as sugar compounds, amine and carboxylic acid (Figure 1), in which the degree of crystallinity reaches 27.34%. While the extractive substance that inhibits gluing is dominated by non-polar chemical compounds of alkyne and ketone, which reaches 47.63% (Figure 2).

The existence of sugar and organic acids compounds, as well as non-polar compounds of the alkyne as an extractive substance in the lignocellulosic material, will inhibit the adhesive reaction with cellulose so that the bonding of adhesive molecules with rattan molecules is not maximal. These results in RLBs, which are easily delaminated when immersed in boiling water. Only RLBs using a synthetic commercial isocyanate adhesive with a glue spread of 100 g/cm² and polyurethane adhesive with a glue spread of 150–200 g/cm² have relatively high bonding strength (20.52–26.33 kg/cm²). The quality of the rattan laminated board is equivalent to the andong (*Gigantochloa pseudoarundinacea*), mayan (*Gigantochloa robusta*) and betung (*Dendrocalamus asper*) bamboo laminated boards, which used tannin adhesive from the merbau wood powder extract (11.87–18.67 kg/cm²) (Santoso et al., 2016a).

The average bonding strength of RLBs glued with various adhesive types and tested in dry condition ranged from 24.52 kg/cm² to 46.16 kg/cm² (Table 2), while RLBs made at pilot scale in PIRNAS-Palu used commercial adhesives (resorcinol) had averaged bonding strength of 35.49 kg/cm² (Santoso et al., 2016b). Based on the data in Table 2, it can be seen that about 52.78% of treatment combinations (19 of 36 combinations) have equal or higher bonding strength value compared to PIRNAS product. The value of RLBs bonding strength are higher than that of glued laminated timber made of sengon wood (18.99 kg/cm²) which uses commercial isocyanate adhesives (Muthmainnah, 2011). However RLBs bonding strength values are similar to the bonding strength of laminated bamboo boards (21.46–33.52 kg/cm²) made from three bamboo species (andong, mayan and betung) glued with natural adhesives from merbau powder extract (Santoso et al., 2016a).

The data on bonding strength was subjected to analysis of variance (Table 3) and the results showed that pre-treatment, glue spread, and adhesive type have significant effect on the bonding strength. The RLBs made from rattan strips which were pre-treated by immersing it in heated kerosene solution (80 kerosene : 20 water) with 150 g/m² glue spread and used tannin based adhesives (particularly TF) have higher bonding strength than commercial adhesive (Table 2). In general, the highest

Table 3. Analysis of variances of bonding strength and formaldehyde emission

Source of variation	df	F-calculation	
		Bonding strength	Formaldehyde emission
Pretreatment, A	1	31.57 ^{hs}	133.22 ^{hs}
Glue spread, B	2	2988.16 ^{hs}	58.61 ^{hs}
Types of adhesive, C	5	1980.43 ^{hs}	468.04 ^{hs}
A * B	2	178.15 ^{hs}	18.02 ^{hs}
A * C	5	1137.89 ^{hs}	77.57 ^{hs}
B * C	10	775.26 ^{hs}	48.95 ^{hs}
A * B * C	10	288.20 ^{hs}	16.38 ^{hs}

Remarks): hs = Highly significant, df = degree of freedom

bonding strength value of RLBs in almost all types of adhesives was reached by applying 200 g/m² glue spread.

In this study, RLBs that use natural adhesives synthesized by incorporating formaldehyde have to be tested regarding formaldehyde emission. The average formaldehyde emissions of RLBs which used natural adhesive ranges from 0.022 mg/L to 3.216 mg/L (Table 2), which is classified as a low-emission product classification (F * – F * * * *). The result of ANOVA in Table 3 shows that pre-treatment, glue spread and adhesive types have significantly affect on formaldehyde emission of RLBs. The best treatment combination in producing RLBs were pre-treatment with kerosene solution (70 kerosene : 30 water) and 150 g/m² glue spread of TRF mangium which resulted in the value of 0.28 mg/L formaldehyde emission and pre-treatment with kerosene solution (80 kerosene : 20 water) and 150 g/m² TF mangium which resulted in the value of 0.78 mg/L formaldehyde emission. Nevertheless, when we consider the formaldehyde emission requirement, the safest treatment combination to produce RLBs for interior purposes was pre-treatment with kerosene solution (80 kerosene : 20 water) glued with TRF mahogany and glue spread of 100 g/m² (0.022 mg/L) and 150 g/m² (0.023 mg/L).

IV. CONCLUSION

Batang rattan (*Calamus zollingeri* Becc.) can be processed into rattan laminated board by using a natural adhesive such as wood bark extract (mangium, mahogany), merbau wood powder, and commercial synthetic adhesives such as isocyanate and polyurethane. The appropriate pre-treatment in producing RLBs for interior furniture was pre-treatment by applying oil heat treatment with kerosene solution (80 kerosene : 20 water) and glued with tannin adhesive of mangium bark extract with glue spread of 200 g/m². Similarly, rattan strips treated with heated oil (80 kerosene : 20 water) and glued with polyurethane adhesive (glue spread of 200

g/m²) produced excellent RLBs for exterior furniture.

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AUTHOR'S CONTRIBUTION

The three authors (AS, IMS and RP) of this article were the main contributors in which the ideas, designs, and experimental designs were carried out by the three authors. Material preparation, experimental and test treatments, and data collection and analysis by AS and RP; manuscript writing by AS, IMS and RP; the revision and finalization of the manuscript was carried out by AS, IMS and RP.

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