The Effect of Gambir Adhesive Level and Hot Press Temperature on Physical and Mechanical Properties of Bamboo Particleboard

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Keywords: Gambir, Adhesive, Bamboo, Particleboard, Properties.

Abstract: Gambir is the extract of leaves sap and young twigs of gambir plants, which contains tannin.Gambir-formaldehyde adhesives have been applied to the particleboards, butsome properties of particleboard produced did not meetthe standard.In this study, gambir adhesives (without formaldehyde) were applied to the bamboo particleboard.The dimension of particleboard was 25x25x1 cm, and the board density target was set at 0.8 g/cm3. Three kinds of adhesive levels (10, 20, 30%) and four kinds of hot-press temperature (160, 180, 200, 220^{o}C) were used for particleboard production. The research aimed to investigatethe effect of gambir adhesive level and hot-press temperature on the physical and mechanical properties of the bambooparticleboard. The physical and mechanical properties of particleboards were then evaluated and compared to the JIS A5908-2003 standard.The study showed that adhesive level and hot-press temperature affected significantly on thickness swelling, water absorption, internal bond, modulus of rupture and modulus of elasticityof particleboard, while the effect of an adhesive level factor was also significant on density properties.Interaction between adhesive level and hot-press temperature factor only affected significantly on water absorption. Particleboards with hot-press temperatures of 200^{o}C and 220^{o}C have better properties than others.The high hot-press temperature has exceeded the melting point of the catechin (174-178^{o}C), furthermore, the gambir adhesive becomes hardened and cured. The most optimal bamboo particleboard is particleboard with 220^{o}C hot-press temperature and adhesive level of 30%, based on the best of particleboard properties compared to JIS A5908-2003.

1 INTRODUCTION

Gambir (*Uncariagambir* (Hunter) Roxb.) in Indonesia are mostly found in West Sumatra and Riau Province (export markets), as well as North Sumatra, Bengkulu, South Sumatra and Aceh (local markets) (Sabarni, 2015; Gumbira-Sa'id*et al.*, 2009). In 2012, gambir commodities in Indonesia with gambir plant area covering 29,326 ha could produce 20,511 tons of dried gambir and exported as many as 15,685 tons worth US$ 34 million(Ministry of Agriculture of Indonesia, 2013).

Gambir is the extract of leaves sap and young twigs of gambir plants, which contain tannin especially tannin from catechins of phenolic groups. Some gambir extract products are processed by the community in various gambir production center in Indonesia. It hasthe catechin content varies from 2.5 to 95% (Amos, 2010).

Many national and global industries need gambir as the main or additional materials in the production process. The factories include the chemical industry, biopharmaceuticals, cosmetics, textiles, leather processing, food and beverages, biopesticides, and metal industries (Ministry of Agriculture of Indonesia, 2013).

The tannins in gambir can also be used as natural adhesives (Pizzi, 1994; Pizzi, 2008).Gambir adhesives combined with formaldehyde have been applied to particleboards from oil palm trunk (Kasim *et al.*, 2007), empty fruit bunches mixture with acacia bark (Fathanah and Sofyana, 2013), and empty fruit bunches (Junaidi*et al.*, 2015).Formaldehyde functions as a cross-linker or hardener, with additions of 10% (Kasim *et al.*, 2007; Junaidi*et al.*, 2015) and

Sucipto, T., Widyorini, R., Prayitno, T. and Lukmandaru, G.
The Effect of Gambir Adhesive Level and Hot Press Temperature on Physical and Mechanical Properties of Bamboo Particleboard.
DOI: 10.5220/0010182800002775
In *Proceedings of the 1st International MIPAnet Conference on Science and Mathematics (IMC-SciMath 2019)*, pages 362-367
ISBN: 978-989-758-556-2

2% (Fathanah and Sofyana, 2013). However, on the other hand, formaldehyde causes formaldehyde emissions, that are toxic and can disrupt the environment and humans (Foyer *et al.*, 2016).

Some physical and mechanical properties of the produced particleboard (Kasim *et al.*, 2007; Fathanah and Sofyana, 2013; Junaidi*et al.*, 2015)did not meet the particleboard standards based on SNI 03-2105-2006. This is thought to be caused by the weakness of material preparation, gambir adhesive formulation, and hot-press process, therefore that the bonding between adhesive and lignocellulose particles was not optimal.

The adhesive level and hot-press temperature affect the quality of the particleboard. As a factor affecting particle board quality, the levels of gambir-formaldehyde adhesives that have been used were 16% (Kasim *et al.*, 2007), 12%, 14%, 16% (Junaidi*et al.*, 2015), and the ratio of gambir to empty fruit bunches (v/v) 30/70, 40/60, 50/50, 60/40 and 70/30 (Fathanah and Sofyana, 2013). The optimal hot-press temperature was 150ºC for 15 min (Kasim *et al.*, 2007; Junaidi*et al.*, 2015) and 145ºC for 30 min (Fathanah and Sofyana, 2013). The particleboard hot-press temperature was less optimal because it is lower than the melting point of the catechin as the main component of the gambir. The melting point of catechins was 174-178ºC (Rahmawati*et al.*, 2012). This means that the gambir adhesive was thought to have not melted to subsequently harden when bonding with lignocellulose particles.

Based on these problems, gambir adhesives (without formaldehyde) were applied to the bamboo particleboard by a factor of adhesive level and hot-press temperature. Betung bamboo wastes from the industry of roof truss components were used as particle materials. Particleboards were tested for the physical and mechanical properties based on JIS A5908-2003 standards. The study aimedto investigate the effect of gambir adhesive level and hot-press temperature on the physical and mechanical properties of bamboo particleboard.

2 MATERIALS AND METHODS

2.1 Materials

Gambirwas purchased from the traditional market and sodium hydroxide (97%) was purchased from Merck. Gambir commonly called gambirbootch, cylindrical form, and dark brown color were used without purification. Each gambir and sodium hydroxide were ground into powder (passes 20-mesh screen).

Betung bamboo (*Dendrocalamus asper*) was used as a particleboard material, originating from the industrial waste of roof truss component in Sleman District, Special Region of Yogyakarta. Bamboo chip wasground into a particle (passes 10-mesh screen) and dried to air-dry condition.

2.2 Methods

2.2.1 Adhesive Formulation

The gambir adhesives were made by dissolving gambir powder in distilled water. The concentration of the solution was adjusted to 45wt%. In each gambir adhesive formulation, the sodium hydroxide solution was added until pH 8 was reached (Kasim *et al.*, 2007).

2.2.2 Particleboard Manufacturing

The particleboard manufacturing consisted of blending, particles and adhesives mix drying at 80ºC for 4 hours, mat-forming, hot-pressing, and conditioning for one week. The dimension of particleboard was 25x25x1 cm, and the board density target was set at 0.8 g/cm^3. Four kinds of hot-press temperature (160ºC, 180ºC, 200ºC, 220ºC) and three kinds of adhesive levels (10%, 20%, 30%) were used for particleboard production.

The boards were pressed at four kinds of temperaturewith a pressure of 3.5 MPa for 10 min.Particleboard pressing used the breathing system (5-1-5 min). The particleboard was then conditioned at room temperature for one week. The gambir adhesives and bamboo particle preparation are summarized in Table 1.

2.2.3 Particleboards Testing

The particleboards were cut into a sample for physical and mechanical properties testing. The sample size used of 5x5 cm (thickness swelling, water absorption, density, and internal bond testing), and 20x5 cm (modulus of rupture and modulus of elasticity testing).

The physical properties of particleboards (thickness swelling, water absorption, and density) and mechanical properties (internal bond, modulus of rupture, and modulus of elasticity) were then evaluated. The board properties were compared to the JIS A5908-2003 standard. The effect of adhesive level and hot-press temperature on the particleboard properties were tested by statistical variance analysis.

Table 1: Preparation of gambir and bamboo particle.

Hot-press temperature (°C)	Adhesive level (%)	Gambir (g)	Distilled water (ml)	NaOH 50% (ml)	Bamboo particle (g)
160	10	45.45	101.00	8	504.54
	20	83.33	185.18	14	462.49
	30	115.38	256.40	19	426.93
180	10	45.45	101.00	8	504.54
	20	83.33	185.18	14	462.49
	30	115.38	256.40	19	426.93
200	10	45.45	101.00	8	504.54
	20	83.33	185.18	14	462.49
	30	115.38	256.40	19	426.93
220	10	45.45	101.00	8	504.54
	20	83.33	185.18	14	462.49
	30	115.38	256.40	19	426.93

3 RESULTS AND DISCUSSIONS

3.1 Physical Properties

The thickness swelling of bamboo particleboard ranged from 13.11% to 131.70%. Figure 1 showed that all the thickness swelling of particleboard did not meet the requirement of JIS A5908-2003 (≤12% of thickness swelling).

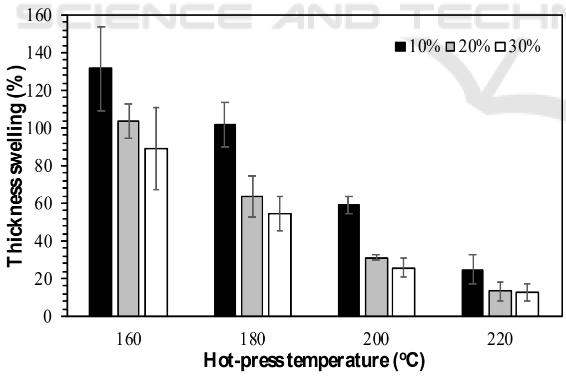

Figure 1: Thickness swelling of particleboard.

In another study, the thickness swelling of bamboo binderless particleboard was below than 12%, to meet the requirement of JIS A5908-2003.The binderless particleboard was hot-pressed on 200°C temperature for 15 min (Widyorini*et al.*, 2011). It might be due to the polar characteristic of gambir tannins (10% to 30%) was applied in this study and a difference in the target of density (0.8 g/cm^3 vs 0.9 g/cm^3). It was reported that catechin is the main chemical component of gambir (Amos, 2010; Hiller and Melzig, 2007).

The factors of adhesive level and hot-press temperature significantly affected the board thickness swelling, while the interaction between two factors was not significant. The high level ofhot-press temperature with the high adhesive level formed a strong bonding between gambir adhesive and bamboo particles.

The particleboard of oil palm trunk used gambir-formaldehyde adhesive obtained thickness swelling properties ranged from 56.98% to 72.63% (Kasim *et al.*, 2007). Consequently, no formaldehyde addition as hardener or cross-linker on gambir adhesive.

The average of particleboard water absorption was 114.34% (Figure 2). Water absorption is usually in line with the thickness swelling, therefore the lower of adhesive level and hot-press temperature will increase the water absorption and thickness swelling properties.

The water absorption of particleboards that meets the FAO standard are particleboards with a hot-press temperature of 220°C (all adhesive level) and 200°C hot-press temperature on adhesive level of 20% and 30%. FAO standards require the particleboard water absorption ranged from 20% to 75%. The factors of adhesive level and hot-press temperature and interaction between two factors were significantly affected on the board water absorption.

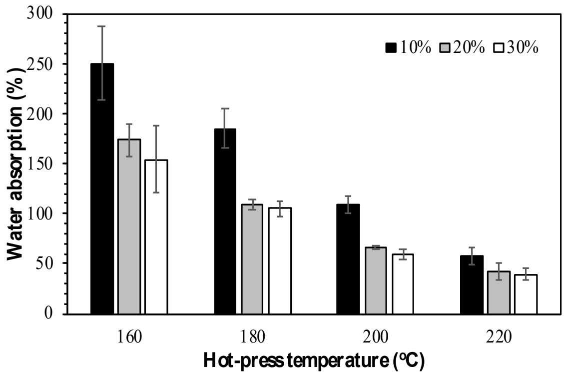

Figure 2: Water absorptionof particleboard.

Figure 3 showed that all the density of particleboardswere ranged from 0.74 g/cm^{3}to 0.83 g/cm^3(average of 0.80 g/cm^3), meet the JIS A5908-2003 requirement.

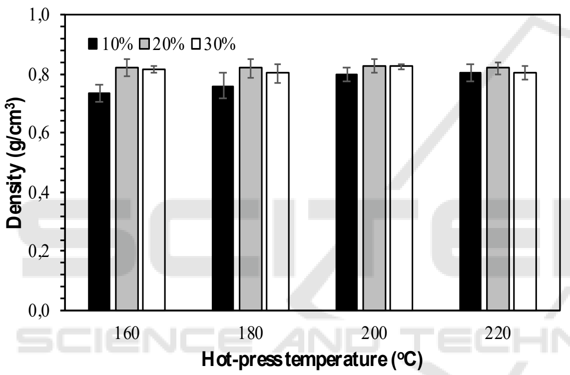

Figure 3: Density of particleboard.

The particleboard density wasappropriated to the density target of 0.80 g/cm^{3}and classified to the medium density particleboard group (0.59-0.80 g/cm^3) (Maloney, 1993). The factors of adhesive level significantly affected the board density, while hot-press temperature factor and interaction between two factors were not significant. Other studies showed that density of particleboard ranged from 0.60g/cm^3 to 0.75 g/cm^3 (density target of 0.7 g/cm^3) (Kasim, 2007) and 0.75-0.85 g/cm^3 (density target of 0.9g/cm^3) (Widyorini*et al.*, 2011).

3.2 Mechanical Properties

The effect of adhesive level and hot-press temperature on internal bond, modulus of rupture and modulus of elasticity of bamboo particleboard are shown in Figure 4, Figure 5, and Figure 6, respectively. The internal bond of bamboo particleboard ranged from 0.03 MPa to 0.70 MPa.

The result showed that the internal bond of bamboo particleboard waslower than the internal bond of oil palm trunk particleboard used gambir-formaldehyde adhesive (0,71-0,81 MPa) (Kasim *et al.*, 2007). Formaldehyde as a cross-linker on gambir adhesive could increase the internal bond of particleboard, even though itcauses toxic emissions for the environment and humans (Foyer *et al.*, 2016).

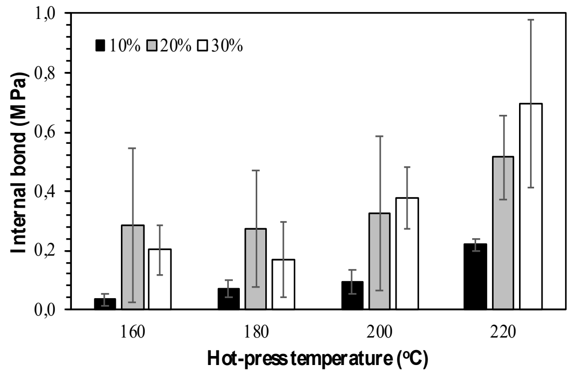

Figure 4: Internal bond of particleboard.

The factors of adhesive level and hot-press temperature significantly affected the board internal bond, while the interaction between two factors was not significant. The result showed that internal bond values meet JIS A5908-2003 requirement for grade 8 types particleboard, on particleboard with the adhesive level of 20% and 30% (all hot-press temperature), plus an adhesive level of 10% (220^{o}C). Particleboards with a hot-press temperature of 200 and 220ºC (adhesive level of 20% and 30%) also meet JIS A5908-2003 (type 18).

The modulus of rupture of bamboo particleboard ranged from 3.13MPa to 14.16MPa (Figure 5).

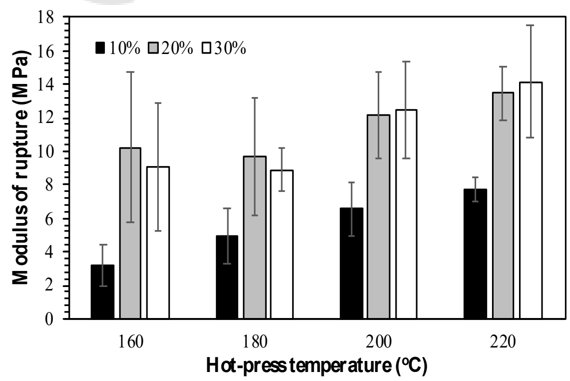

Figure 5: Modulus of rupture of particleboard.

The interaction between two factors was not significantly affected the board modulus of rupture, while the factors of adhesive level and hot-press temperature significantly affected the modulus of rupture properties. Particleboards with all hot-press temperature (adhesive level of 20% and 30%) were met JIS A5908-2003 (type 8). Particleboard grade 13 type only fulfilled by particleboards with hot press temperature of 220^{o}C (adhesive level of 20% and 30%).

Figure 6 showed that the modulus of elasticity of bamboo particleboard ranged from 0.68 GPa to 3.21 GPa (average of 2.24 GPa).

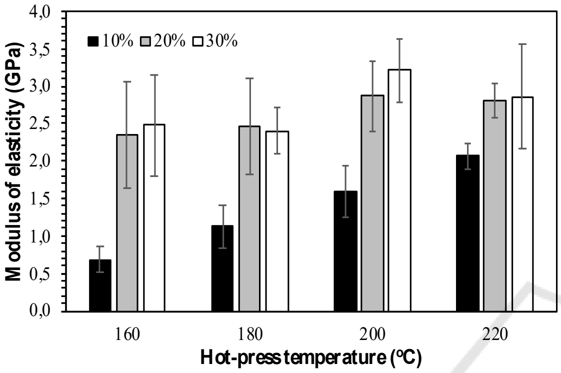

Figure 6: Modulus of elasticity of particleboard.

Particleboard that meets JIS A5908-2003 (type 8) requirement for modulus of elasticity were all particleboard with the adhesive level of 20% and 30%, plus one particleboard with the adhesive level of 10% on 220^{o}C hot-press temperature.

For JIS A5908-2003 (type 8)fulfilled by particleboards with a hot-press temperature of 200 and 220^{o}C (adhesive level of 20% and 30%).The one and only particleboard with a hot-press temperature of 200^{o}C on adhesive level of 30%were meet JIS A5908-2003 (type 18).

The factors of adhesive level and hot-press temperature significantly affected the board modulus of elasticity, while the interaction between two factors was not significant.

3.3 The Optimal Physical and Mechanical Properties of Particleboards

The physical and mechanical properties of bamboo particleboards compared with JIS A5908-2003 and statistical analysis are summarized in Table 2. The most optimal bamboo particleboard is particleboard with 220^{o}C hot-press temperature and adhesive level of 30%, based on the best values of the physical and mechanical properties of particleboard compared to JIS A5908-2003.

Table 2: The physical and mechanical properties of particleboards compared with JIS A5908-2003 and statistical analysis.

Hot-press temperature (^{o}C)	Adhesive level (%)	Physical properties			Mechanical properties		
		TS (%)	WA (%)	D (g/cm^3)	IB (MPa)	MOR (MPa)	MOE (GPa)
160	10	131.70 (a)	250.29 (a)	0.74)18 (c)	0.03 (d)	3.19 (e)	0.68 (e)
	20	103.66 (b)	173.33 (bc)	0.82)18 (a)	0.28)13 (bcd)	10.24)8 (abc)	2.35)8 (abc)
	30	89.10 (b)	154.05 (c)	0.81)18 (ab)	0.20)13 (cd)	9.05)8 (abcd)	2.48)8 (abc)
180	10	101.79 (b)	184.96 (b)	0.76)18 (bc)	0.07 (cd)	4.95 (de)	1.12 (de)
	20	63.58 (c)	109.40 (d)	0.82)18 (a)	0.27)13 (bcd)	9.71)8 (abcd)	2.47)8 (abc)
	30	54.69 (c)	104.98 (d)	0.80)18 (ab)	0.17)8 (cd)	8.88)8 (abcd)	2.40)8 (abc)
200	10	59.38 (c)	108.87 (d)	0.80)18 (ab)	0.09 (cd)	6.55 (cde)	1.60 (cd)
	20	31.20 (d)	66.35 (e)	0.83)18 (a)	0.33)18 (bcd)	12.17)8 (ab)	2.87)13 (ab)
	30	25.85 (d)	59.06 (e)	0.83)18 (a)	0.38)18 (bc)	12.49)8 (ab)	3.21)18 (a)
220	10	24.78 (d)	57.09 (e)	0.80)18 (ab)	0.22)13 (bcd)	7.70 (bcde)	2.07)8 (bc)
	20	13.31 (d)	41.36 (e)	0.82)18 (a)	0.51)18 (ab)	13.45)13 (a)	2.81)13 (ab)
	30	13.11 (d)	38.82 (e)	0.80)18 (ab)	0.70)18 (a)	14.16)13 (ab)	2.86)13 (ab)
JIS A5908-2003	Type 8	≤12	20-75*	0.4–0.9	≥0.15	≥8	≥2
	Type 13				≥0.2	≥13	≥2.5
	Type 18				≥0.3	≥18	≥3

Description:
- *FAO standard.
-)8meet JIS A5908-2003 type 8;)13meet JIS A5908-2003 type 13;)18meet JIS A5908-2003 type 18.
- numbers followed by the same letters (in parentheses) mean that they are not significantly different.

4 CONCLUSIONS

- Gambir could be used as the natural adhesive for particleboard, that can meet most of the JIS A5908-2003 requirements. Adhesive level and hot-press temperature factor affected significantly on thickness swelling, water absorption, internal bond, modulus of rupture and modulus of elasticity of particleboard, whilethe effect of an adhesive level factor was also significant on the density of particleboard.Interaction between adhesive level and hot press temperature factor only affected significantly on water absorption of particleboard.
- Particleboards with hot-press temperatures of 200°C and 220°C have better properties than others. Particleboards with the adhesive level of 20% and 30% also have better properties than 10%.The high hot-press temperature has exceeded the melting point of the catechin (174-178°C), therefore the gambir adhesive becomes hardened and cured. The most optimal bamboo particleboard is particleboard with 220°C hot-press temperature and adhesive level of 30%, based on the best of particleboard properties compared to JIS A5908-2003.

ACKNOWLEDGMENTS

The authors are grateful for the financial support from The Indonesia Endowment Fund for Education (LPDP) and The Ministry of Research, Technology, and Higher Education of Indonesia.

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