Properties of Laminated Wood Bonded with Modified Gutta-Percha Adhesive at Various Surface Roughness Profile of Laminae

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The properties of laminated wood prepared from sengon wood (*Falcataria moluccana* Miq. Barneby & Grimes) bonded with a modified gutta-percha (MGP) adhesive at various laminae surface roughness profiles were investigated. The wood laminae were sanded using sand papers of KAG grit designation of 80, 100, 150, 220, 300, and 400. A lower value of KAG grit designation with a lager particle size of sand resulted in a rougher surface of the bonded laminae; a rougher laminae surface profile resulted in a greater shear strength of the laminated wood. The shear strength was highest for laminated wood treated with sand paper of KAG 80 and smallest for laminated wood treated with KAG 400. In general, the bonding strength was enhanced with decreasing KAG grit designation. The adhesion performance, in terms of spread and adhesive penetration, improved after sanding, which widened the contact area on the wood surface.

Keywords: Adhesive; Gutta-percha; Grit designation; Laminated wood; Surface roughness

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INTRODUCTION

Wood adhesives are an essential element in the efficient manufacture of forest products. One type of raw material for wood adhesives that is environmentally friendly and renewable is gutta-percha (*trans*-1, 4-isoprene rubber), particularly that sourced from the extracted leaves and tapped stems of palaquium trees *(Palaquium oblongifolium* Burck). Gutta-percha based adhesives can be used in plywood and laminated wood (Febrianto *et al.* 2006; Karliati *et al.* 2014).

The bonding compatibility of wood adhesives depends on the species of wood, chemical and physical properties, bonding surface conditions, adhesive characteristics, *etc*. (Vazquez *et al.* 2003). Prayitno (2000) found that the internal factors of the wood materials, including the wood structure and anatomy, material density, moisture content, and surface properties, influence the gluing process. Petrie (2007) suggested that the important features of successful adhesion were surface cleanliness, wetting (intimate contact and adhesive dispersion on substrate surfaces), adhesive hardening, pressure-resistant and environmental-resistant bond formation, and control of all the materials and manufacturing processes. One important parameter affecting bonding strength is the surface roughness of a wood material (Cumble and Darekar 2017). For instance, liquid adhesives can penetrate through rough surfaces and contribute to stickiness through mechanical locking action. For this reason, increasing the shear strength on the side of the material to be glued can be achieved through sanding, a process that improves the wood surface roughness (Sulaiman *et al.* 2009).

Several studies of surface roughness treatment have been related to wettability, contact angle, adhesion quality, and interfacial adhesion (Belfas *et al.* 1993; Matuana *et al*. 1998; Vazquez *et al.* 2003; Meiron *et al.* 2004; Kilic *et al*. 2006; Ayrilmis *et al.* 2010; Budhe *et al*. 2015; Söğütlü. 2017). With regard to improving wettability and adhesive quality by wood surface roughness, this research aims to evaluate the performance of laminated wood prepared from sengon wood (*Falcataria moluccana* Miq. Barneby & Grimes) bonded with a modified gutta-percha (MGP) adhesive at various laminae surface roughness profiles.

EXPERIMENTAL

Materials

Gutta-percha containing 95.10% gutta was supplied by PT Perkebunan Nusantara (PTPN) VIII Sukabumi, Indonesia, while the 8-year-old sengon wood (*Falcataria moluccana* Miq. Barneby & Grimes), with an average density of 0.34 g/cm^3, was obtained from Institut Teknologi Bandung, Jatinangor Campus, West Java, Indonesia.

Methods

Evaluation of wood laminae surface profiles

Laminae specimens with dimensions of 200 mm (length) × 80 mm (width) × 10 mm (thickness) were dried at 60 °C until a constant moisture content of 9 to 10% was reached. Their surfaces were sanded via a sanding machine loaded with sand paper of varying grit designations of aluminum oxide as follows: KAG (surface roughness profile using grit designation of sand paper) 80, 100, 150, 220, 300, and 400. The roughness profiles of the laminae surfaces after sanding were evaluated using a stereo microscope (Nikon SMZ 745 ST, Tokyo, Japan) with 10× magnification.

Preparation of a modified gutta-percha adhesive

The modified gutta-percha (MGP) adhesive was prepared as follows. Gutta-percha granules with 5% maleic anhydride (MAH) were dissolved into toluene at a 22.5:77.5 ratio (gutta-percha:toluene; w/w). The solution was then heated in a 70 °C hot water bath for 10 min while being stirred and was allowed to cool for 24 h. Benzoyl peroxide (BPO; 1%) was added to the adhesive as an initiator before application to the laminated wood panel.

Characterization of MGP adhesive

The physical characteristics of the MGP adhesive, namely solids content, appearance, specific gravity, and viscosity, were evaluated according to SNI-06-0060-1998 (BSN 1998). Its contact angle on the wood surface was captured every 10 s for 1 min with a camera (Canon EOS 600) and Motic Image Plus Version 2.0 software (Motic China Group Co., Ltd., Xiamen, China).

Manufacture and evaluation of laminated wood

Two laminar pieces (whose dimensions were stated above) with a moisture content of 9 to 10% were bonded with the MGP adhesive. A roll bar was used to make the glue spread to be 300 g/cm^2 on two surfaces of lamina and the target thickness of glue line was 0.1 mm. The laminae were assembled in parallel and then pressed under 5 kg/cm^2 of pressure for 24 h at room temperature. The laminated woods were conditioned for 7 d before testing.

The properties of the laminated wood, including moisture content, density, shear strength, and delamination ratio, were evaluated according to JAS 234 (JPIC 2003). A block shear test (shear area of 6.25 cm^{-2}) was conducted in dry and wet conditions *via* a universal testing machine (United Testing System Inc., Fullerton, CA, USA). In the wet condition tests, the laminated wood was soaked in 60 °C water for 3 h, followed by a 6-h soak in cold water.

The glue line thickness of the laminated wood bonded with MGP was measured with a digital microscope 5V DC USB 2.0 model with cooling technology software (Ningbo Handa Precision Equipment Co., Ltd., Zhejiang, China)

Data analysis

The laminated wood properties were analyzed using analysis of variance (ANOVA) with Duncan's multiple range tests at a 95% confidence interval. Data analyses were conducted with Statistical Analysis System (SAS) version 9.1 (SAS Institute, Cary, NC, USA).

RESULTS AND DISCUSSION

MGP Adhesive Characteristics

Figure 1 shows the MGP adhesive, which appeared beige in color. Its specific gravity, viscosity, and solids content were 0.9, 84 poise, and 23.9%, respectively, which were similar to the values reported by Karliati *et al.* (2014).

Fig. 1. MGP adhesive (in beige color)

Roughness Profile of Laminae Surface

Figure 2 shows the different roughness profiles of the laminae surfaces after sanding with sand paper of different grit designations of KAG 80, 100, 150, 220, 300, and 400.

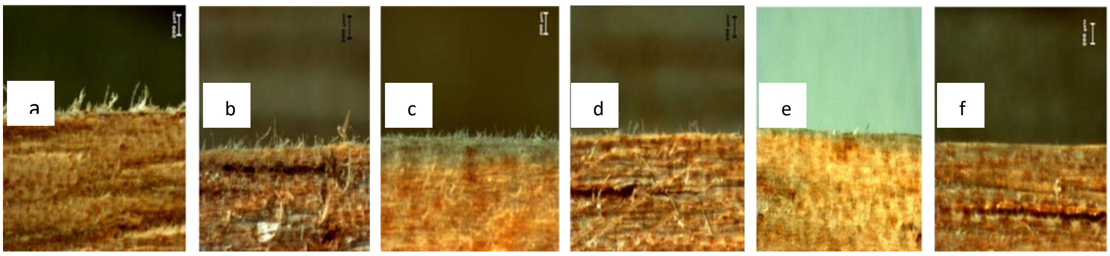

Fig. 2. Roughness profiles of laminae surface sanded by different grit designations: (a) KAG 80, (b) KAG 100, (c) KAG 150, (d) KAG 220, (e) KAG 300, and (f) KAG 400

The surfaces sanded with sand paper of grit designation 80 exhibited the roughest profile, while those sanded with a grit designation of 400 had the smoothest surface. In general, the roughness of the laminae surfaces increased with decreasing grit designation. This result was similar to previous studies (Sulaiman *et al.* 2009; Ayrilmis *et al.* 2010). Kalio *et al.* (2013) reported that the surface roughness of composites decreased from 0.41 to 0.04 µm when the grit designation was changed from 320 to 2400.

MGP Adhesive Contact Angle

The contact angle of the MGP adhesive was measured to determine its compatibility with the laminae. The measured contact angles at various laminae surface roughness profiles after sanding are presented in Table 1, while the relationship between observation time and adhesive contact angle is shown in Fig. 3.

Table 1. Contact Angle (°) of MGP Adhesive on Various Laminae Surface Sanded with Different Grit Designations

Grit designations	Elapsed time (s)							Δ (60-0) (s)
	0	10	20	30	40	50	60	
KAG 80	95.90	66.25	55.80	50.55	43.00	38.40	30.35	65.55
KAG 100	98.10	68.60	60.25	52.95	48.05	39.65	34.55	63.55
KAG 150	98.70	67.90	60.05	52.85	45.55	41.00	36.40	62.30
KAG 220	99.95	67.70	61.25	55.55	50.85	42.35	38.80	62.15
KAG 300	101.30	69.10	60.80	56.00	47.10	41.50	39.55	62.00
KAG 400	102.70	71.65	59.35	50.30	46.90	42.85	42.55	60.15

The contact angle of the adhesive ranged from 95.1° to 102.7°. The MGP adhesive is hydrophobic/non-polar, characterized by non-polar polymers and typically having a larger contact angle than polar natural fibers (Hwang *et al.* 2007). Thus, a rougher surface profile would produce a smaller contact angle compared with a smoother surface profile. The contact angle of MGP at the laminae surface sanded with KAG 80 was lower than that with KAG 400. In general, the contact angle decreased with increased observation time for 60 s (Fig. 3), with the highest decrease observed with sanding at KAG 80 grit designation.

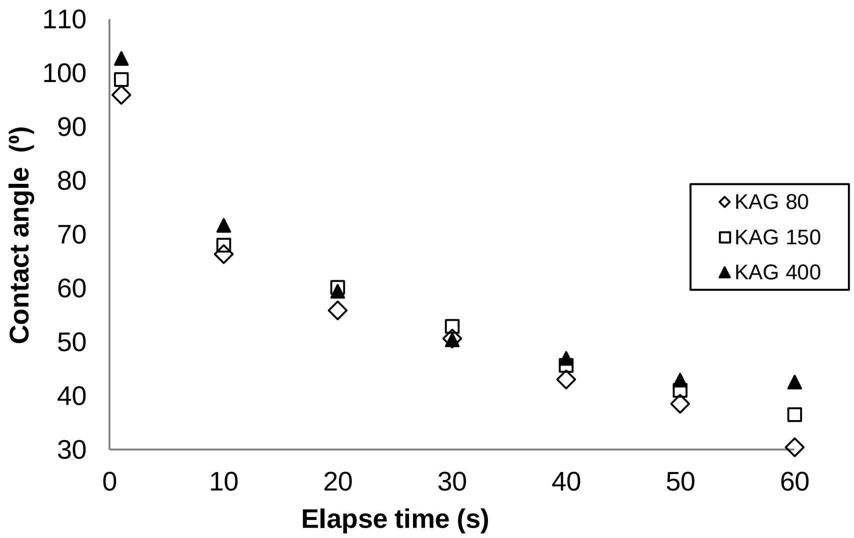

Fig. 3. Relationship between observation time and contact angle of MGP adhesive at laminae surface sanded by different grit designations

Sanding used lower grit designation yielded higher surface roughness with a lower contact angle (Meiron *et al.* 2004; Kilic *et al.* 2006; Sulaiman *et al.* 2009; Airylmis *et al.* 2010). Thus, a lower contact angle for the liquid leads to greater wettability of the solid by the liquid (Mera and Duncan 2005). Furthermore, Belfas *et al*. (1993) reported that increases in wettability were produced by sanding with 80 grit designation sand paper relative to rougher surface yield.

Moisture Content and Density of Laminated Wood

The moisture contents of laminated woods prepared from laminae with various surface roughness profiles and MGP adhesives ranged from 12.6 to 13.0%, while their density ranged from 0.39 to 0.40 g/cm³ (Table 2). Thus, the moisture content met the JAS standard (moisture content lower than 14%). In contrast, the density was greater than that of solid wood (0.34 g/cm³), which may have resulted from the adhesive addition and pressing during manufacture of the laminated wood (Febrianto *et al.* 2006; Karliati *et al.* 2014).

Table 2. Moisture Content and Density of Laminated Wood with Various Laminae Surface sanded by Different Grit Designations

Surface Roughness Profile of Laminae	Density (g/cm^3)	Moisture Content (%)
KAG 80	0.40±0.005	12.63± 0.60
KAG 100	0.40±0.002	12.76± 0.42
KAG 150	0.40±0.007	12.87± 0.42
KAG 220	0.40±0.009	12.95± 0.40
KAG 300	0.39±0.008	12.89± 0.42
KAG 400	0.39±0.005	12.75± 0.36

The ANOVA results validated that surface roughness profiles of the laminae did not significantly influence the density and moisture content of laminated wood at $\alpha = 0.05$, which indicates that the treatment had no direct effect. The slightly larger density values for the rougher surfaces might then have been related to the glue line thickness of the MGP adhesive.

Shear Strength and Delamination Ratio of Laminated Wood

Figure 5 shows the shear strengths of the laminated wood in dry and wet conditions. For the laminated wood subjected to the dry test, to wet conditions in cold water soaking for 6 h, and to hot water soaking at 60 °C, the shear strengths ranged from 4.37 to 5.18 N/mm^2, 2.17 to 2.53 N/mm^2, and 1.49 to 1.82 N/mm^2, respectively. For all conditions, the shear strength was greatest in the samples treated with KAG 80 and lowest in the samples treated with KAG 400. The increased surface roughness profile of wood laminae improved the shear strength in the grit designation order KAG 80 > KAG 100 > KAG 150 > KAG 220 > KAG 300 > KAG 400. Similarly, Kureli and Doganav (2015) reported that the decrease in the roughness of MDF surface from 3.32 ụm to 2.85 ụm reduced the shear strength by as much as 11%.

The shear strength values of laminated wood subjected to the dry test were higher than those subjected to the wet conditions, and this result coincided with that of the previous research. Belfas *et al.* (1993) reported that wood surface roughness using a sand paper of grit designation 80 increased the shear strength in dry tests. In the wet tests, shear strength decreased with increasing sand paper grit designation. The strength loss might have been due to weakening adhesive bonds as stress developed from the dimensional changes of wood laminae during soaking.

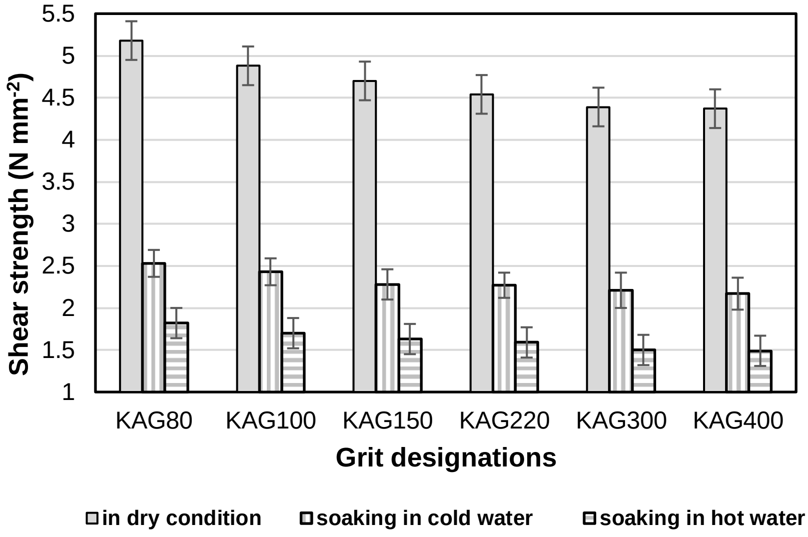

Fig. 4. Shear strength of laminated woods with various laminae surface sanded by different grit designations in dry and wet conditions

The results of the shear strength analysis showed that in the dry conditions test, surface roughness had a significant effect on shear strength at α = 0.05, while the effect was not significant on shear strength in the wet conditions. A Duncan's multiple-area dry test showed that the results did not differ for KAG 80, KAG 100, and KAG 150, nor did they differ for KAG 220, KAG 300, and KAG 400. In contrast, the results between these two sets were different.

Figure 5 shows the delamination ratio of laminated wood bonded with MGP, varying within 0 to 0.67%. The surface roughness of the laminae had no significant effect on the delamination ratio at α = 0.05.

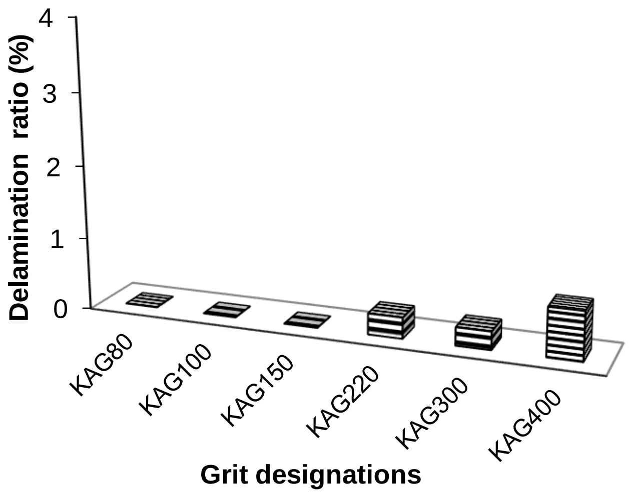

Fig. 5. Delamination ratio of laminated woods with various laminae surface sanded by different grit designations

The laminated wood with a rougher surface had higher shear strengths and lower delamination ratios, a phenomenon believed to be related to the contact angle between the MGP adhesive and the wood laminae surface. To some extent, the laminated wood with high surface roughness had smaller contact angles (Vazquez *et al*. 2003). Moreover, contact angle measurements can be used to estimate the wettability of materials (Meiron *et al.* 2004; Alamsyah *et al.* 2007), which is another factor affecting the quality of the adhesive (Warsa 1983; Prayitno 2000), aside from the discussed surface roughness. During the tests, the wettability was affected by the resulting surface roughness associated with sand paper grit. Improved adhesion quality was realized after reduction of surface contaminants by sanding, and the increased contact area improved the spread and penetration of the adhesive.

In both dry and wet condition tests, the higher shear strength and lower delamination ratios in the coarser laminae surfaces (KAG 80) were related to the thickness of the glue line. The rougher surfaces had wider contact areas, which affected the spread and penetration of the adhesive. Intimate contact between the adhesive and the surface occurred in the sanded wood material, hence, the boundaries between the actual glue line of the adhesive and the wood were barely visible in the sanded structures of the glue line (Belfas *et al.* 1993).

Table 3 and Fig. 6 present the glue line thickness at various wood laminae surface roughness profiles, which varied from 0.059 to 0.101 mm, in the following order of sand paper grit designation: KAG 80 > KAG 100 > KAG 150 > KAG 220 > KAG 300 > KAG 400. The laminated wood treated with KAG 80 had the thickest glue line, while that treated with KAG 400 had the thinnest. Thus, the rougher the wood laminae surface, the wider the contact area. This was thought to be related to the area of contact in the spread and the penetration of the adhesive.

Table 3. Glue Line Thickness of Laminated Wood at Various Laminae Surface Roughness Profiles

Surface Roughness Profile of Laminae	Glue Line Thickness (mm)
KAG 80	0.101 ± 0.006
KAG 100	0.091 ± 0.003
KAG150	0.081 ± 0.004
KAG 220	0.077 ± 0.004
KAG 300	0.067 ± 0.012
KAG 400	0.059 ± 0.005

In general, the glue line thickness for wood adhesion was within 0.13 to 0.18 mm (Marra 1992). Kurt (2006) reported that a thicker glue line (0.1 to 0.3 mm) was associated with a decrease in the shear strength of laminated wood. Hajdarevic (2012) verified that the increase in glue line thickness in the ranges of 0.18 to 0.48 mm and 0.1 to 0.5 mm (Tsoumis 1991) caused shear strength to decrease.

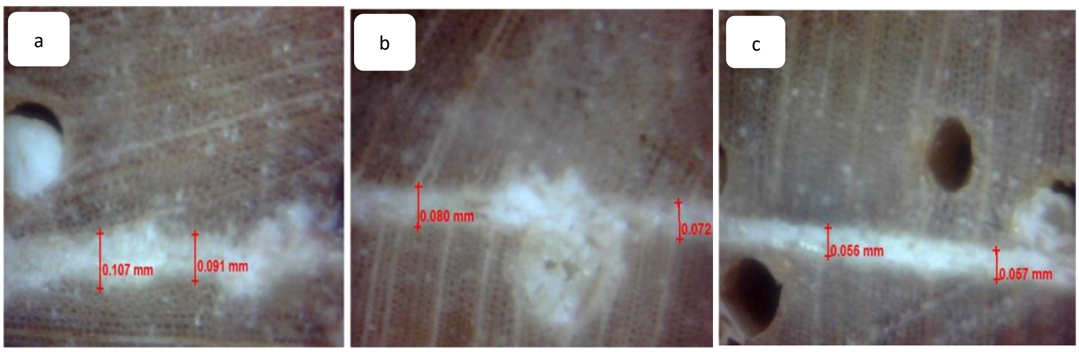

Fig. 6. Digital micrographs of glue line thickness with different laminae surface sanded by different grit designations: (a) KAG 80, (b) KAG 150, and (c) KAG 400

CONCLUSIONS

1. The sanding of wood using sand paper with a smaller grit designation led to a rougher the surface of the laminae to be bonded. The surface roughness profile of the laminae influenced the performance of the laminated wood bonded with the MGP adhesive.
2. The rougher surface profile of the laminae led to greater shear strength in the laminated wood. The highest shear strength was obtained with the sand paper of grit designation 80 (KAG 80), whereas the smallest was with KAG 400.
3. Improved adhesion was realized after sanding, which widened the contact area and improved the spreading and penetration of the adhesive. The contact angle of the MGP adhesive affected the bondability of laminated wood.

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