

Research Article

Eka Mulya Alamsyah*, Yoyo Suhaya, Sutrisno, Yayat Hidayat, Takashi Tanaka, Masaaki Yamada

Investigation of the adhesion performance of some fast-growing wood species based on their wettability

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Abstract: The objective of this study was to investigate the adhesion performance of eight fast-growing wood species, namely, *Enterolobium cyclocarpum*, *Paraserianthes falcataria*, *Shorea* sp., *Toona sinensis*, *Gmelina arborea*, *Pinus merkusii*, *Acacia mangium*, and *Acacia hybrid* obtained from the tropical region. The wettability test was conducted by contact angle measurement, while the adhesion performance was expressed by strength retention (SR) and wood failure (WF) percentages through block shear tested under the Japanese Agricultural Standard (JAS). Results showed that smaller contact angle for *P. falcataria* followed by *E. cyclocarpum*, *P. merkusii*, *T. sinensis*, and *Shorea* indicated that the surfaces were easier to be glued than that of *G. arborea*, *A. mangium*, and *A. hybrid*. It is indicated that high wettability of *P. falcataria*, *E. cyclocarpum*, *P. merkusii*, *T. sinensis*, and *Shorea* resulted in the better adhesive spread and more intimate contact between the wood surface and the adhesive as shown by their high SR with high WF percentages.

Keywords: adhesion, fast-growing, performance, wettability, wood

1 Introduction

The performance of the adhesive joint is determined by the physical and mechanical conditions of the surface of the material because the adhesive has a function to glue two surface areas. Therefore, before the wood is glued, the surface condition of the wood must meet several criteria, such as a smooth, even texture, free from dirt, free from machine marks, no raised or peeled fibers, and others. Pretreatment such as drying and evaporation given to the wood to be glued should not be excessive so that it diffuses to the surface because it will pollute and permanently close the pores of the wood cells. Chemically the surface of the wood can become inactive during the bonding process due to chemical contamination in the surrounding air, chemical components, and extractive substances that block the gluing process, oxidation, and pyrolysis due to excessive drying, the addition of preservatives to the adhesive, the addition of fire retardants to the adhesive, and the addition of other chemicals. Overall, the one that has the most negative effect is the presence of extractive substances because it can be a major contributor to the inactivation of the wood surface, which ultimately causes the ability of the wood to absorb the adhesive to be reduced. This is especially true for resin species, such as southern pine and Douglas-fir. Currently, the most common solvent used in the adhesive is water. In some of wood species that contain an extractive substance, this makes it difficult for the adhesive to wet the surface, it flows so that it is difficult to penetrate the pores. This is in line with the statement that the acidity of several hardwood species and oaks from Southeast Asia can interfere with the bonding process (Vick 1999). To determine the ability of a material in the bonding process, it is necessary to understand its density, acidity (pH), and the level of wettability of the material itself (Freeman 1959). The approach taken to determine the surface wettability of wood is to refer to the rate or

* **Corresponding author: Eka Mulya Alamsyah**, Post Harvest Technology Study Program, School of Life Sciences and Technology, Institut Teknologi Bandung, Jl. Ganesa 10, Bandung 40132, West Java, Indonesia, e-mail: ekamulya@sith.itb.ac.id

Yoyo Suhaya: Post Harvest Technology Study Program, School of Life Sciences and Technology, Institut Teknologi Bandung, Jl. Ganesa 10, Bandung 40132, West Java, Indonesia

Sutrisno, Yayat Hidayat: Forestry Engineering Study Program, School of Life Sciences and Technology, Institut Teknologi Bandung, Jl. Ganesa 10, Bandung 40132, West Java, Indonesia

Takashi Tanaka, Masaaki Yamada: Laboratory of Wood Adhesion, Department of Bioresource Science, Faculty of Agriculture, Shizuoka University, 836 Ohya, Suruga-ku, Shizuoka-shi, 422-8529, Japan

how fast the liquid can wet and spread on the surface and be absorbed into the pores (Wellons 1980).

The wetting and spreading of the liquid involve the principles of surface tension and thermodynamics. Wettability is a quick method for predicting the gluability of unknown species, which can be measured by determining the contact angle between the solid–liquid interface and liquid–air surface (Bodig 1962). The contact angle is defined as the angle formed between the wood surface that is free of the liquid and the curved line of the liquid. When the absorption energy on the wood surface is high, the contact angle will be close to zero, and at the same time, the affinity value and the adhesive surface tension are low. If we drop a certain amount of adhesive and spread it to form a thin film layer so that the contact angle is close to zero degrees, the adhesive will spread well and form a strong contact with the surface area it is attached to (Vick 1999).

Wood is one of the main commodities in Indonesia, which is needed as a raw material for various needs that continue to increase. However, now wood production from natural forests is decreasing due to the high rate of deforestation compared to the rate of planting and community forest areas. Shifting attention to types of plantation and community forest wood with fast-growing wood species is one effort that can be done to overcome the limited supply of wood, especially as raw material for the wood processing industry (Karina 2003; Marsoem 2004; Subiyanto and Firmanti 2004; Alamsyah et al. 2006; Alamsyah et al. 2007; Alamsyah et al. 2008; Alamsyah et al. 2018; Alamsyah et al. 2020; Sutrisno et al. 2019). Laminated wood made from fast-growing wood is intended to meet the shortage of sawn wood supply and becomes the potential material for structural purposes. However, to make this potential successful, the study

on the adhesion performance based on the wettability was done. The wettability test was performed through contact angle measurement, while the adhesion performance was expressed by strength retention (SR) and wood failure (WF) percentages through block shear tested under the Japanese Agricultural Standard (JAS).

2 Materials and methods

2.1 Materials

2.1.1 Wood species

Wood species used were *Enterolobium cyclocarpum* (EC), *Paraserianthes falcataria* (PF), *Toona sinensis* (TS), *Gmelina arborea* (GA), *Pinus merkusii* (PM), *Acacia mangium* (AM), *Shorea* Roxb. (S), and *Acacia hybrid* (AH). Detailed information about the characteristics of these wood species is presented in Table 1.

2.1.2 Adhesive types

Four types of commercial resin adhesives were used in this study. They were polyvinyl acetate emulsion (PVAc), urea formaldehyde (UF), aqueous polymer isocyanate (API), and resorcinol formaldehyde (RF). PVAc and UF are widely used in Indonesia for housing purpose and plywood production, while API and RF are commonly used for glulam production in Japan. The adhesive mixing process was carried out according to the supplier's instructions. Detailed information about the adhesive preparation is presented in Table 2.

Table 1: Wood species

| Species | Symbol | Age (year) | Diameter (cm) | Height (m) | Density (g/cm ³) | MC (%) |
|----------------------------------|--------|------------|---------------|------------|------------------------------|--------|
| <i>Enterolobium cyclocarpum</i> | EC | 7 | 28 | 11 | 0.30 | 9.5 |
| <i>Paraserianthes falcataria</i> | PF | 8 | 30 | 10 | 0.34 | 9.3 |
| <i>Shorea</i> sp. | S | n/a | n/a | n/a | 0.47 | 12.0 |
| <i>Toona sinensis</i> | TS | 11 | 11 | 10 | 0.49 | 9.0 |
| <i>Gmelina arborea</i> | GA | 11 | 28 | 10 | 0.51 | 9.3 |
| <i>Pinus merkusii</i> | PM | 11 | 23 | 12 | 0.59 | 9.3 |
| <i>Acacia mangium</i> | AM | 7 | 31 | 10 | 0.64 | 9.0 |
| <i>Acacia hybrid</i> | AH | n/a | n/a | n/a | 0.70 | 12.0 |

MC, moisture content.

Table 2: Adhesives

| Type | Glue mixture composition (pbw) | Spread rate (g/m ²) |
|------|--|---------------------------------|
| PVAc | — | 200 |
| UF | Resin (100):NH ₄ Cl 20% (15):flour (10) | 300 |
| API | Resin (100):cross link agent (15) | 250 |
| RF | Resin (100):hardener (15) | 250 |

Pbw, parts by weight

2.2 Methods

2.2.1 Wettability measurement

A wettability test was conducted using contact-angle meter (CA-DT type A) (Kyowa Interface Co., Ltd, 1990). 60 × 20 × 5 mm specimens were cut from boards that had previously been smoothened using a planer machine. The specimens were placed on a sliding glass and conditioned at room temperature of 20°C and 65% RH for 24 h. A total of 0.20 mL distilled water (pH 5.76) was dropped onto the specimen surface at room temperature (29.5°C). Then, the contact angle was observed and measured every 10 s for 2 min of testing. The number of replications was five for each type of wood.

2.2.2 Bondability measurement

2.2.2.1 Laminated wood manufacturing

All double-layered laminates were manufactured from laminates containing heartwood and sapwood. Laminae with a size of 230 × 120 × 10 mm were smoothened using a machine planed and conditioned at a room temperature of 20°C and 65% RH for 24 h. A weighed amount of adhesive was applied to both surfaces of the laminae using a roller, followed immediately by the precise assembly. The pressure load was applied at 0.98 MPa for EC, PF, S, TS, GA, and PM laminates and at 1.18 MPa for AM and AH at a room temperature for 24 h. Before testing, laminated wood was conditioned at room temperature for 7 days.

2.2.2.2 Shear strength test

Small shear specimens were cut from double-layered laminates bonded with test adhesives. The shear strength test was carried out simultaneously with the failure test of the wood by following the JAS (2000) under normal

conditions. As a comparison, the shear strength of the wood itself was also studied. Each type of the wood for each type of adhesive had a number of repetitions of 10 (a total of 320 specimens). The universal testing machine (UTM) was used in the shear strength test with a load rate of about 9.8 kN/min until failure occurs. The shear strength and strength retention were calculated using the following equations:

$$\text{Shear strength (kgf/cm}^2\text{)} = \frac{\text{Maximum load at failure}}{\text{Glued area}} \quad (1)$$

$$\text{Strength retention (\%)} = \frac{\text{Bond shear strength}}{\text{Wood shear strength}} \times 100. \quad (2)$$

Wood failure was estimated at 0–100% of glued area. Then, bondability of the specimens was classified into four categories: excellent (80–100% both retention of strength and wood failure), good (60–79%), poor (40–59%), and very poor (0–39%) (Alamsyah et al. 2007). Specimens with excellent and good classification are indications of better adhesive penetration and easier bonding.

2.2.3 Statistical analysis

The complete randomized design of 8 × 4 (eight wood species and four adhesive types) was used to determine the significant differences between the treatments (wood species and adhesive types) and their effects on the measured parameters (contact angle, strength retention, shear strength, and wood failure). Data analysis was performed to test the difference between treatments using the Duncan test using SPSS version 16 software.

3 Results and discussion

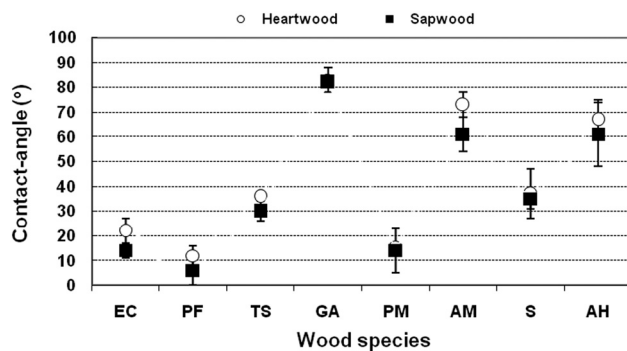
3.1 Wettability

The measurement results of the change in the contact angle for 120 s for each type of wood are presented in Table 3 and Figure 1. The measurement values show a decrease in the contact angle over time as soon as the liquid is dropped on the measured laminae surface as presented in Table 3. In the heartwood (H) specimen, the average contact angle of the water droplet at 20 s observation time for *E. cyclocarpum*, *P. falcata*, *T. sinensis*,

Table 3: Contact angle value during measurement for 120 s

| Wood species | Part | Elapsed time (s) | | | | | | | | | | | |
|--------------|------|------------------|----|----|----|----|----|----|----|----|-----|-----|-----|
| | | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
| EC | H | 26 | 22 | 18 | 16 | 14 | 12 | 11 | 9 | 8 | 8 | 5 | 4 |
| | S | 20 | 14 | 10 | 7 | 5 | 2 | 1 | 1 | 1 | 1 | 0 | 0 |
| PF | H | 16 | 12 | 7 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | S | 16 | 6 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TS | H | 40 | 36 | 34 | 31 | 30 | 29 | 28 | 27 | 26 | 26 | 25 | 25 |
| | S | 33 | 30 | 28 | 26 | 25 | 24 | 23 | 23 | 22 | 21 | 21 | 20 |
| GA | H | 88 | 83 | 80 | 78 | 76 | 73 | 71 | 69 | 68 | 67 | 66 | 65 |
| | S | 83 | 82 | 79 | 77 | 73 | 72 | 70 | 68 | 66 | 65 | 63 | 61 |
| PM | H | 19 | 15 | 12 | 9 | 5 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | S | 22 | 14 | 8 | 5 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| AM | H | 79 | 73 | 69 | 67 | 66 | 65 | 64 | 63 | 63 | 62 | 61 | 61 |
| | S | 64 | 61 | 58 | 56 | 55 | 54 | 53 | 52 | 51 | 50 | 50 | 49 |
| S | H | 41 | 37 | 36 | 36 | 35 | 34 | 32 | 31 | 30 | 28 | 26 | 26 |
| | S | 38 | 36 | 35 | 34 | 34 | 33 | 32 | 31 | 30 | 28 | 27 | 25 |
| AH | H | 68 | 67 | 66 | 64 | 62 | 60 | 59 | 59 | 59 | 58 | 58 | 58 |
| | S | 62 | 61 | 60 | 59 | 57 | 57 | 56 | 55 | 54 | 54 | 54 | 53 |

H, heartwood; S, sapwood.

**Figure 1:** Contact angle value in average.

G. arborea, *P. merkusii*, *A. mangium*, *Shorea*, and *A. hybrid* was 22, 12, 36, 83, 15, 73, 37, and 67°, respectively. In sapwood (S), the average contact angle of water droplet at 20 s observation time for *E. cyclocarpum*, *P. falcata*, *T. sinensis*, *G. arborea*, *P. merkusii*, *A. mangium*, *Shorea*, and *A. hybrid* was 14, 6, 30, 82, 14, 61, 36, and 61°, respectively (Figure 1). Furthermore, the water droplets on the surface of *E. cyclocarpum*, *P. falcata*, and *P. merkusii* were absorbed, and the contact angle was close to zero after 70 s in *E. cyclocarpum*, after 50 s in *P. falcata* and after 60 s in *P. merkusii*. Conversely, on *G. arborea*, *A. mangium*, and *A. hybrid*, the droplets remained as the initial conditions were

dropped on the laminae surface, and the contact angle had not approached zero for 2 min of observation time. Similar high contact angles for *G. arborea* and *A. mangium* have been reported by Hirabayashi and Nakano (1997). They reported that the contact angles of *G. arborea* and *A. mangium* from Malaysia were 82 and 70°, respectively, and there was no downward trend during the observation period. The lower absorption of water droplets by *G. arborea*, *A. mangium*, and *A. hybrid* can be attributed to the wood extractive component. It is predicted that the extractive components of *G. arborea*, *A. mangium*, and *A. hybrid* can cover the surface and cause surface inactivation. Extensive research shows that extractives on wood surfaces are the main physical and chemical contributors to surface inactivation, resulting in poor wettability by adhesives. This is especially true for resin species, such as southern pine and Douglas-fir. Other reasons are the most wood adhesives contain water as a carrier; therefore, they do not properly wet, flow, and penetrate the extractive covered surface. The extractive acidity of some Southeast Asian hardwood and oak species can interfere with the chemical reaction of adhesives (Bodig 1962). In contrast, the smaller contact angles for *P. falcata* followed by *E. cyclocarpum*, *P. merkusii*, *T. sinensis*, and *Shorea* indicated that the surface was easier to wet compared to *G. arborea*, *A. mangium*, and *A. hybrid*.

Table 4: Parameters measuring in laminated wood bonded with PVAc adhesive

| Wood species | Value | PVAc adhesive | | | |
|--------------|---------|------------------------------|----------------|------------------|------------------------|
| | | Density (g/cm ³) | Strength (MPa) | Wood failure (%) | Strength retention (%) |
| EC | Average | 0.39 | 6.27 | 100.00 | 86.89 |
| | St Dev | 0.04 | 0.82 | 0.00 | 22.06 |
| PF | Average | 0.32 | 7.98 | 100.00 | 77.37 |
| | St Dev | 0.05 | 0.65 | 0.00 | 11.53 |
| S | Average | 0.41 | 9.73 | 100.00 | 91.82 |
| | St Dev | 0.04 | 1.85 | 0.00 | 19.72 |
| TS | Average | 0.55 | 18.34 | 91.00 | 112.49 |
| | St Dev | 0.03 | 3.01 | 9.94 | 19.47 |
| GA | Average | 0.49 | 11.39 | 34.00 | 74.24 |
| | St Dev | 0.01 | 2.91 | 19.55 | 20.05 |
| PM | Average | 0.62 | 10.38 | 13.50 | 61.04 |
| | St Dev | 0.01 | 0.73 | 7.47 | 9.11 |
| AM | Average | 0.72 | 14.00 | 11.00 | 77.64 |
| | St Dev | 0.03 | 3.28 | 8.10 | 19.03 |
| AH | Average | 0.77 | 21.54 | 28.00 | 113.58 |
| | St Dev | 0.04 | 3.03 | 22.51 | 16.27 |

Table 5: Parameters measuring in laminated wood bonded with UF adhesive

| Wood species | Value | UF adhesive | | | |
|--------------|---------|------------------------------|----------------|------------------|------------------------|
| | | Density (g/cm ³) | Strength (MPa) | Wood failure (%) | Strength retention (%) |
| EC | Average | 0.41 | 9.50 | 100.00 | 131.15 |
| | St Dev | 0.02 | 1.23 | 0.00 | 31.16 |
| PF | Average | 0.30 | 7.50 | 100.00 | 72.78 |
| | St Dev | 0.02 | 0.82 | 0.00 | 12.47 |
| S | Average | 0.47 | 8.36 | 100.00 | 78.86 |
| | St Dev | 0.02 | 0.84 | 0.00 | 11.33 |
| TS | Average | 0.50 | 16.33 | 91.00 | 99.90 |
| | St Dev | 0.02 | 1.73 | 8.76 | 8.76 |
| GA | Average | 0.48 | 12.33 | 62.00 | 81.04 |
| | St Dev | 0.02 | 0.67 | 33.27 | 12.39 |
| PM | Average | 0.61 | 15.86 | 96.00 | 92.79 |
| | St Dev | 0.04 | 1.88 | 6.99 | 13.08 |
| AM | Average | 0.62 | 15.49 | 64.00 | 86.07 |
| | St Dev | 0.05 | 2.12 | 30.26 | 14.06 |
| AH | Average | 0.72 | 12.48 | 38.00 | 65.82 |
| | St Dev | 0.05 | 2.58 | 24.40 | 14.44 |

3.2 Bondability

The results of parameter measurement of the laminated wood bonded with each adhesives type are presented in Tables 4–7. Among wood species used, the density values from the lowest to the highest were *P. falcataria*, *E. cyclocarpum*, *Shorea*, *G. arborea*, *T. sinensis*, *P. merkusii*, *A. mangium*, and *A. hybrid*. The density of the laminated wood bonded with API was not significantly different from UF. The density of the laminated wood bonded with RF was not significantly different from PVAc. The density of the laminated wood bonded with RF and PVAc was significantly different from the density of the laminated wood bonded with API and UF. The type of wood, the type of adhesive, and its interactions had a very significant effect on the laminated wood density. The shear strength values from the lowest to the highest were *E. cyclocarpum*, *P. falcataria*, *Shorea*, *G. arborea*, *P. merkusii*, *A. mangium*, *T. sinensis*, and *A. hybrid*. The type of wood had a very significant effect on shear strength, but the type of adhesive had no effect on its shear strength. The interaction between wood species and adhesive types had a very significant effect on the shear strength. Among wood species used, the wood failure values from the lowest to the highest were *A. hybrid* and *A. mangium*; *G. arborea* and *P. merkusii*; *T. sinensis*; *P. falcataria*, *Shorea*, and *E. cyclocarpum*. The values of wood failure of *A. hybrid* and *A. mangium*

were not different, the value of wood failure of *G. arborea* with *P. merkusii* was not different, and wood failure values of *P. falcataria* with *Shorea* and *E. cyclocarpum* did not differ. Among adhesive types used, wood failure of the laminated wood bonded with PVAc was not

Table 6: Parameters measuring in laminated wood bonded with API adhesive

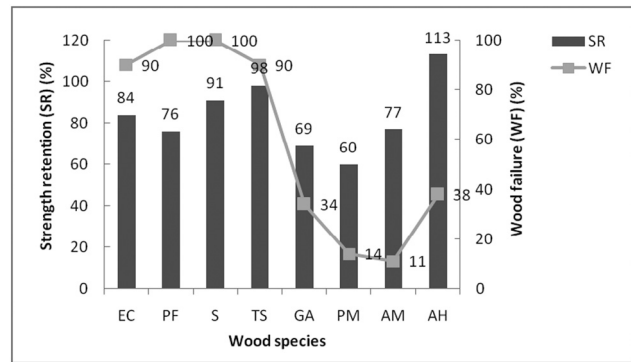
| Wood species | Value | API adhesive | | | |
|--------------|---------|------------------------------|----------------|------------------|------------------------|
| | | Density (g/cm ³) | Strength (MPa) | Wood failure (%) | Strength retention (%) |
| EC | Average | 0.32 | 7.25 | 99.00 | 100.73 |
| | St Dev | 0.02 | 0.54 | 3.16 | 22.59 |
| PF | Average | 0.34 | 9.40 | 98.00 | 90.92 |
| | St Dev | 0.03 | 1.28 | 6.32 | 15.62 |
| S | Average | 0.48 | 10.03 | 100.00 | 94.38 |
| | St Dev | 0.02 | 1.23 | 0.00 | 13.43 |
| TS | Average | 0.52 | 15.98 | 93.00 | 98.03 |
| | St Dev | 0.03 | 2.57 | 6.75 | 15.98 |
| GA | Average | 0.48 | 9.53 | 61.00 | 62.59 |
| | St Dev | 0.02 | 2.77 | 28.07 | 20.35 |
| PM | Average | 0.57 | 13.29 | 65.00 | 77.79 |
| | St Dev | 0.07 | 3.54 | 30.28 | 21.66 |
| AM | Average | 0.65 | 18.21 | 43.00 | 101.26 |
| | St Dev | 0.06 | 3.04 | 24.97 | 18.96 |
| AH | Average | 0.74 | 19.63 | 55.00 | 103.95 |
| | St Dev | 0.04 | 3.07 | 33.75 | 19.00 |

Table 7: Parameters measuring in laminated wood bonded with RF adhesive

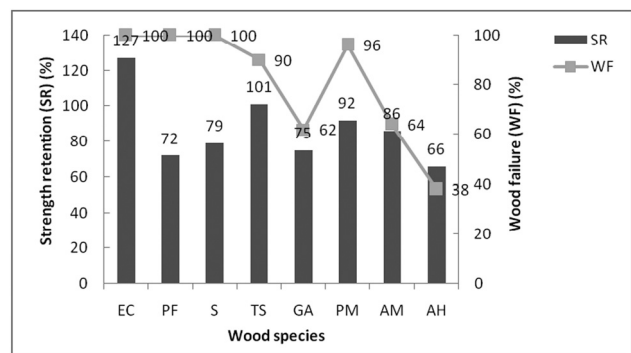
| Wood species | Value | RF adhesive | | | |
|--------------|---------|------------------------------|----------------|------------------|------------------------|
| | | Density (g/cm ³) | Strength (MPa) | Wood failure (%) | Strength retention (%) |
| EC | Average | 0.40 | 8.30 | 100.00 | 118.04 |
| | St Dev | 0.04 | 1.86 | 0.00 | 44.28 |
| PF | Average | 0.39 | 8.87 | 84.00 | 84.97 |
| | St Dev | 0.03 | 1.80 | 26.33 | 14.09 |
| S | Average | 0.49 | 9.71 | 89.00 | 90.96 |
| | St Dev | 0.02 | 0.96 | 12.87 | 6.44 |
| TS | Average | 0.52 | 15.44 | 60.00 | 94.65 |
| | St Dev | 0.01 | 2.88 | 22.61 | 17.46 |
| GA | Average | 0.50 | 11.84 | 62.00 | 77.62 |
| | St Dev | 0.03 | 2.11 | 25.30 | 17.01 |
| PM | Average | 0.55 | 15.14 | 52.00 | 88.20 |
| | St Dev | 0.02 | 2.24 | 28.21 | 12.54 |
| AM | Average | 0.63 | 13.66 | 22.00 | 75.55 |
| | St Dev | 0.04 | 3.62 | 16.19 | 18.50 |
| AH | Average | 0.76 | 16.56 | 14.00 | 87.61 |
| | St Dev | 0.04 | 1.56 | 6.99 | 11.58 |

significantly different from RF. Wood failure of the laminated wood bonded with API was not significantly different from UF. Wood failure of the laminated wood bonded with RF and PVAc was significantly different from wood failure of the laminated wood bonded with API and UF. Wood failure of the laminated wood bonded with RF and PVAc was lower than wood failure of the laminated wood bonded with API and UF. The type of wood species, the type of adhesive, and its interactions had a very significant effect on wood failure percentages. The strength retention value of *G. arborea* was not different from *P. merkusii* and *P. falcata*. The strength retention value of *P. merkusii* was not different from *P. falcata* and *A. mangium*. The strength retention value of *P. falcata* was not different from *A. mangium* and *Shorea*. The strength retention value of *A. mangium* was not different from *Shorea* and *A. hybrid*. The strength retention value of *T. sinensis* was not different from *E. cyclocarpum*. Wood species had a very significant effect on strength retention, but the type of adhesive had no effect on strength retention. The interaction between wood species and adhesive types had a very significant effect on strength retention.

Furthermore, in the laminated wood bonded with PVAc (Figure 2), results show that excellent bondability was achieved by *E. cyclocarpum*, *Shorea* sp., and *T. sinensis*, while good bondability was achieved by *P. falcata*. Poor and very poor bondability were achieved by

**Figure 2:** Strength retention (SR) and wood failure (WF) percentages of the laminated wood bonded with PVAc.

G. arborea, *P. merkusii*, *A. mangium*, and *A. hybrid*. In the laminated wood bonded with UF (Figure 3), results show that excellent bondability was achieved by *E. cyclocarpum*, *T. sinensis*, and *P. merkusii*, while good bondability was obtained by *P. falcata*, *Shorea* sp., *A. mangium*, and *G. arborea*. Poor bondability was achieved by *A. hybrid*. For the laminates bonded with API (Figure 4), results showed that excellent bondability was achieved by *E. cyclocarpum*, *P. falcata*, *Shorea*, and *T. sinensis*, while good bondability was achieved by *P. merkusii* and *A. mangium*. Poor bondability was achieved by *G. arborea* and *A. hybrid*. Figure 5 shows that in the laminates bonded with RF, excellent bondability was achieved by *E. cyclocarpum*, *P. falcata*, and *Shorea*, while good bondability was achieved by *T. sinensis* and *G. arborea*. Poor bondability was achieved by *P. merkusii*, while very poor bondability was achieved by *A. mangium* and *A. hybrid*. In this study, the interaction between wood species and adhesive types had a very significant effect on strength retention. The results also indicated that high wettability for *P. falcata*, *E.*

**Figure 3:** Strength retention (SR) and wood failure (WF) percentages of the laminated wood bonded with UF.

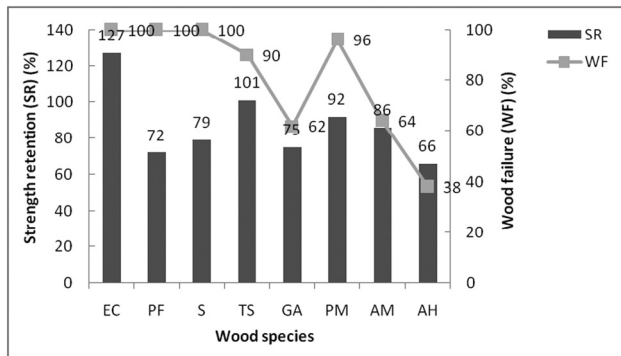


Figure 4: Strength retention (SR) and wood failure (WF) percentages of the laminated wood bonded with API.

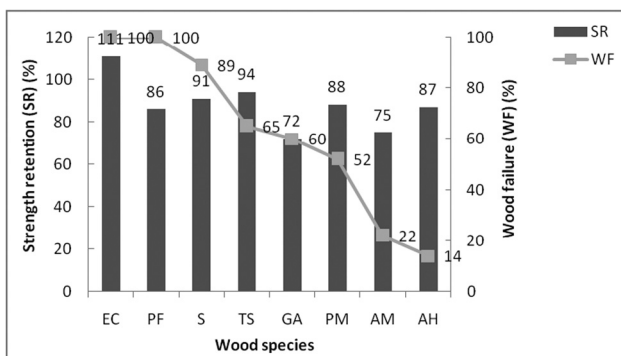


Figure 5: Strength retention (SR) and wood failure (WF) percentages of the laminated wood bonded with RF.

cyclocarpum, *P. merkusii*, *T. sinensis*, and *Shorea* resulted in the better adhesive spread and more intimate contact between the wood surfaces and adhesives showing by their high strength retention with high wood failure percentages.

4 Conclusion

Smaller contact angle for *P. falcataria* followed by *E. cyclocarpum*, *P. merkusii*, *T. sinensis*, and *Shorea* suggested that the surfaces of the wood were easier to be glued than that of *G. arborea*, *A. mangium*, and *A. hybrid*. It is indicated that high wettability of *P. falcataria*, *E. cyclocarpum*, *P. merkusii*, *T. sinensis*, and *Shorea* resulted in the better adhesive spread and more intimate contact between the wood surface and adhesive by showing their high strength retention with high wood failure percentages.

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