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# Bond Shear Strength of Sungkai (*Peronema canescens Jack*) Laminated Wood Based on Adhesive Type and Bonding Plane

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A R T I C L E I N F O

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A B S T R A C T

This study aimed to analyze the bond shear strength of sungkai glued laminated timber (glulam) subjected to three adhesive treatments (A), namely polyvinyl acetate (PVAc), epoxy, and polyester adhesives, and two bonding plane orientations (B), namely radial–radial (R–R) and tangential–tangential (T–T). The bond shear strength was tested in accordance with the BS EN 14080:2013 and JAS 234:2007 standard. Statistical analysis was performed using analysis of variance (ANOVA) with a two-way 3 × 2 factorial design in a Completely Randomized Design (CRD), with 15 replication for each treatment, followed by the Least Significant Difference (LSD) test for mean comparison. The ANOVA results showed that the adhesive type (A), bonding plane orientation (B), and their interaction (AB) had highly significant effects on the bonding shear strength of sungkai glulam. Based on adhesive type, the highest mean bond shear strength was obtained with PVAc adhesive (a1), at 5.70 N/mm², followed by epoxy adhesive (a2), at 5.20 N/mm², while the lowest value was obtained with polyester adhesive (a3), at 2.33 N/mm². The tangential–tangential bonding plane orientation (b2) resulted in a higher mean bond shear strength of 5.73 N/mm² compared with the radial–radial orientation (b1), which yielded 3.09 N/mm². The results showed that the combination of PVAc adhesive and tangential–tangential bonding-plane orientation (a1b2) produced the highest bond shear strength, at 9.52 N/mm², thereby satisfying the minimum requirements of 4.8 N/mm² specified in BS EN 14080:2013 and 5.4 N/mm² specified in JAS 234:2007. In contrast, polyester adhesive failed to meet the requirements of either standard for both bonding-plane combinations

## INTRODUCTION

The demand for wood as a construction material continues to increase, while the availability of wood in suitable sizes and qualities is becoming increasingly limited. The application of glulam technology provides an alternative approach to addressing this issue. According to (Suardika et al., 2023), glued laminated timber (glulam) is produced by bonding several pieces of wood together with an adhesive to form larger-sized boards or beams as an engineered wood product. Glulam technology enables the utilization of small-diameter timber or wood of relatively low quality, thereby improving the efficiency of wood resource utilization (Subuh et al., 2020).

Sungkai (Peronema canescens Jack), also known as jati sabrang, is a timber species widely utilized for various purposes, including furniture, building materials (boards), handicrafts such as sculptures and carvings, building construction components (floors and walls), and plywood production. The grain of sungkai wood produces an attractive figure. The wood is light brown in the central portion, while the outer portion is light reddish-brown or grayish, with edges that are lighter in color than the central portion, giving it a grain pattern resembling that of teak (Tectona grandis) (Dayacipta, 2022). Sungkai wood is classified as strength class II–III and durability class III (Tanubrata, 2015). These characteristics indicate that sungkai has potential for development into glulam products, particularly to enhance its utilization in applications requiring specific dimensions, forms, and strength properties.

The successful production of glulam is determined not only by the characteristics of the wood but also by the quality of the adhesive bond at the bonding interface. Bonding performance is influenced by various factors, including adhesive type, wood moisture content, temperature, and pressing time (Setiawan et al., 2014). Therefore, selecting an appropriate adhesive is essential because the adhesive bond serves to transfer loads between the wood laminations and consequently determines the quality and strength of the resulting bond.

Polyvinyl acetate (PVAc), epoxy, and polyester are adhesive types that are relatively readily available on the market and are widely used for various wood-bonding applications; however, they possess different bonding characteristics. PVAc is commonly used in woodworking applications because it is easy to apply and provides good bonding performance on porous materials such as wood. Epoxy and polyester adhesives are capable of forming strong adhesive bonds and producing effective joints with a wide range of materials. However, epoxy is generally recognized as having higher strength and better moisture resistance than polyester. Polyester has more limited applications, particularly in bonding handicraft products and non-structural composite panels, whereas PVAc and epoxy are commonly regarded as versatile adhesives for structural construction and glulam applications (Putra, (2025); Supraptono, (2014). These differences in adhesive characteristics are expected to result in different bonding performance in the manufacture of sungkai glulam.

The orientation of the wood bonding surface is a factor that has received relatively little attention. Differences in wood anatomical structure between the

radial and tangential planes may affect the bonding process and the strength of the resulting adhesive bond. Cahyono et al., (2017) explained that the radial plane is perpendicular to the wood rays, whereas the tangential plane is parallel to the wood rays. Differences in the characteristics of these two planes may result in differences in their ability to withstand and transfer shear loads.

## LITERATURE REVIEW

Although the effects of adhesive type and bonding-plane orientation have received attention in glulam research, a comparative study of the bonding response of sungkai wood (Peronema canescens Jack) to different adhesive types and bonding-plane orientations has not yet been reported. This study evaluated three adhesive types (PVAc, epoxy, and polyester) and two bonding-plane combinations (radial–radial and tangential–tangential). The effects of adhesive type and bonding-plane orientation, as well as the interaction between these two factors, on the bond shear strength of sungkai glulam were analyzed. An earlier study by (Pujianto, 2023) showed that sungkai glulam exhibited higher tensile strength than solid sungkai wood, indicating its potential as an alternative material for wooden boat hulls.

Based on the foregoing, it is necessary to investigate the effects of adhesive type and bonding-plane orientation on the bond shear strength of sungkai glulam. The resulting bond shear strength will subsequently be evaluated against the requirements of BS EN 14080:2013 (Structural glued laminated timber and glued solid timber) and JAS 234:2007 (Structural glued laminated timber). The findings are expected to provide a reference for the future production and application of sungkai glulam.

## METHODS

### Research Procedures

The wood log of Sungkai with a diameter of approximately 25 cm, obtained from PT. Idea Borneo, Jl. Gunung Belah No. 64, Tenggarong, East Kalimantan, was sawn into radial and tangential boards measuring 3 × 6 × 120 cm. The boards were then air-dried for one month and subsequently conditioned in a controlled environment (constant room) at a temperature of 20 ± 1°C and a relative humidity of 65 ± 3% until reaching a normal moisture content (<15%), in accordance with the requirements of BS EN 14080:2013 and JAS 234:2007.

The boards were subsequently fabricated into glulam by applying three different adhesive types, namely PVAc, epoxy, and polyester, to both surfaces of the boards to be bonded (double glue spreading). Two bonding-plane combinations were used: radial–radial and tangential–tangential, with a spread rate of 200 g/m². The boards were pressed at room temperature under a pressure of 10 bar for 3 hours. The laminated wood was then conditioned at room temperature for 2 days to allow the adhesive bond to fully cure. The laminated wood was subsequently planed to obtain specimens measuring 5 × 5 × 120 cm and then cut into 5 × 5 × 5 cm specimens for determining bond shear strength in accordance with the testing standards specified in BS EN 14080:2013 and JAS 234:2007.

All test specimens were subsequently reconditioned in a constant room at a temperature of 20 ± 1°C and a relative humidity of 65 ± 3% until reaching the moisture content (normal dry moisture content) required for bond shear strength testing according to BS EN 14080:2013 and JAS 234:2007, namely <12%.

Bond shear strength testing was performed using a Wolpert Lestor Universal Testing Machine (UTM), Type MPDI C Series. The moisture content (1), wood density (2), bond shear strength (3), and wood failure percentage (%WF) (4) were determined in accordance with BS EN 14080:2013 and JAS 234:2007 using the following equations:

$$MC = \frac{mn-m0}{m0} \times 100\ (\%) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

MC = Normal Dry Moisture Content (%)
mn = Normal Dry Weight Test Specimen (g)
m0 = Oven-Dry Test Specimen Weight (g)

$$\rho_n = \frac{mn}{vn}(\mathrm{g/cm^3}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

ρn = Normal Dry Wood Density (g/cm3)
mn = Normal Dry Weight Test Specimen (g)
vn = Normal Dry Volume Test Specimen ($cm^3$)

$$\tau s = \frac{\text{F maks}}{\text{A}}(\mathrm{N/mm^2}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

τs = Bond Shear Strength ($N/mm^2$)
F maks = Maximum Load (N)
A = Bonding Surface Area Test Specimen ($mm^2$)

$$\text{WF\%} = \frac{\text{F}}{\text{A}} \text{ x } 100\ (\%) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

KK = Wood Failure (%)
F = Wood Failure Surface Area ($mm^2$)
A = Bonding Surface Area Test Specimen ($mm^2$)



Figure 1. Bond Shear Strength Test of Sungkai Glulam Specimen.

**Data Analysis**

A two-way analysis of variance (ANOVA) was conducted using a 3 × 2 factorial experimental design at confidence levels of 95% and 99%, with 15 replicates for each treatment combination, to determine whether the treatments had significant effects. When a significant or highly significant treatment effect was detected, a post hoc analysis was performed using the Least Significant Difference (LSD) test to determine differences among the levels within each treatment.

Table 1. Research Treatments and Parameter.

| Bonding Plane (B) | Adhesive Type (A) | | |
|---|---|---|---|
| | PVAc ($a_1$) | Epoxy ($a_2$) | Polyester ($a_3$) |
| Radial-Radial (R-R) ($b_1$) | $a_1b_1$ | $a_1b_2$ | $a_3b_1$ |
| Tangential-Tangential (T-T) ($b_2$) | $a_2b_1$ | $a_2b_2$ | $a_3b_2$ |

Note : R = Radial plane ; T = Tangential Plane

## RESULTS AND DISCUSSION

### Moisture Content And Density of Sungkai Wood Raw Material

The mean of normal dry moisture content and density of sungkai wood boards measuring 3 × 6 × 120 cm, prior to the bonding process, are presented in the following table:

Table 2. Mean of Normal Dry Moisture Content and Density of Sungkai Wood Boards Prior to the Bonding Process.

| Adhesive type (A) | PVAc (a1) | | Epoxy (a2) | | Polyester (a3) | |
|---|---|---|---|---|---|---|
| Bonding plane (B) | R-R (b1) | T-T (b2) | R-R (b1) | T-T (b2) | R-R (b1) | T-T (b2) |
| MC normal dry (%) | 11,25 | 11,42 | 11,00 | 11,00 | 11,25 | 10,75 |
| ρ (g/cm$^3$) | 0,46 | 0,45 | 0,46 | 0,46 | 0,45 | 0,42 |
| CV MC (%) | 2,09 | 5,07 | 2,15 | 3,20 | 2,10 | 3,09 |
| CV ρ (%) | 0,82 | 0,52 | 0,92 | 0,92 | 0,48 | 1,15 |

Note : CV = Coefficient of Variation ; MC = Moisture Content ; ρ = Wood Density

The mean moisture content of the conditioned (normal dry) sungkai wood boards prior to the bonding process was relatively uniform, ranging from 10.75% to 11.25%. The coefficient of variation (CV) was also relatively low and consistent, ranging from 2.09% to 5.07%, indicating that conditioning the sungkai wood boards in a constant room had achieved an equilibrium moisture content under normal conditions. The moisture content of the boards met the requirements specified in BS EN 14080:2013 and JAS 234:2007 prior to bonding into glulam, namely <15%. Uniform and appropriate moisture content is essential for achieving good bonding quality in wood. Ruhendi et al., (2007) stated that high moisture content in wood can inhibit adhesive penetration because the wood has a lower absorption capacity, making it more difficult for the adhesive to penetrate into the wood structure.

The mean normal dry density of the sungkai wood boards after conditioning in a controlled environment ranged from 0.42 to 0.46 g/cm$^3$. Based

on its density, sungkai wood is classified as a low-density wood, with a density of <0.6 g/cm³ (Dumanauw, 2007). According to the Kementerian LHK, (2020), the air-dry density of sungkai wood is 0.58 g/cm³, and based on its density, it is classified as strength class III–IV. The lower measured density values are attributed to differences in the moisture conditioning conditions. Under air-dry moisture conditions, the wood contains a higher amount of water, resulting in a higher air-dry density than the density measured under normal dry moisture conditions.

**Moisture Content and Density of Sungkai Glulam**

The mean normal dry moisture content and density of the sungkai glulam test specimens measuring 5 × 5 × 5 cm at the time of bond shear strength testing are presented in the following table:

Table 3. Mean Normal Dry Moisture Content and Density of Sungkai Glulam Specimens at Bond Shear Strength Testing.

| Adhesive type (A) | PVAc (a1) | | Epoxy (a2) | | Polyester (a3) | |
|---|---|---|---|---|---|---|
| Bonding plane (B) | R-R (b1) | T-T (b2) | R-R (b1) | T-T (b2) | R-R (b1) | T-T (b2) |
| MC normal dry (%) | 11,88 | 11,92 | 11,51 | 11,86 | 11,94 | 11,57 |
| ρ (g/cm³) | 0,47 | 0,46 | 0,47 | 0,47 | 0,46 | 0,46 |
| CV MC (%) | 1,04 | 0,95 | 0,93 | 0,59 | 3,23 | 0,94 |
| CV ρ (%) | 0,22 | 0,35 | 0,32 | 0,39 | 0,19 | 0,51 |

Note : CV = Coefficient of Variation; MC = Moisture Content ; ρ = Density of Speciemens

The mean normal dry moisture content of the sungkai glulam specimens at the time of bond shear strength testing ranged from 11.51% to 11.94%. The coefficient of variation (CV) was relatively low, ranging from 0.93% to 3.23%, indicating a high degree of uniformity in moisture content. These values met the requirements of BS EN 14080:2013 (8–15%) and JAS 234:2007 (<12%). The relatively uniform moisture content within the specified range indicates that the moisture conditions of the test specimens were adequately controlled during testing; therefore, the potential effect of moisture content on bond shear strength measurements can be considered negligible. Wood moisture content affects the strength of adhesive-bonded joints, with high moisture content reported to reduce bond shear strength by up to 43% (Sugiman, 2014).

The mean normal dry density of the sungkai wood used as the raw material showed an increase of approximately 0.1–0.4 g/cm³ from the pre-bonding condition to the condition at the time of bond shear strength testing. This increase was attributed to the mass of adhesive that penetrated into the wood during the pressing process in glulam manufacture (Somadona et al., 2020). The mean density of the sungkai glulam specimens at the time of bond shear strength testing was highly uniform, ranging from 0.46 to 0.47 g/cm³, as also indicated by the very low coefficient of variation (CV) values of 0.19–0.51%. This uniformity indicates that differences in glulam density did not significantly affect the bond shear strength test results.

**Bond Shear Strength Test of Sungkai Glulam**

The mean bond shear strength of sungkai glulam, together with the analysis of variance (ANOVA) and Least Significant Difference (LSD) test results for the applied treatments, is presented in the following table:

Table 4. Mean Bond Shear Strength Test (N/mm²) of Sungkai Glulam Specimens Based on Adhesive Type and Bonding Plane Orientation.

| Treatments | PVAc (a1) | | Epoxy (a2) | | Polyester (a3) | | Mean τs (N/mm²) |
|---|---|---|---|---|---|---|---|
| | τs | CV (%) | τs | CV (%) | τs | CV (%) | |
| R-R (b1) | 1,87 | 72,65 | 4,92 | 29,82 | 2,48 | 69,18 | 3,09 |
| T-T (b2) | 9,52 | 12,58 | 5,48 | 17,44 | 2,18 | 44,25 | 5,73 |
| Mean τs (N/mm²) | 5,70 | - | 5,20 | - | 2,33 | - | |

Note : CV = Coefficient of Variation ; τs = Bond strength Test

Table 5. ANOVA of Bond Shear Strength (N/mm²) of Sungkai Glulam Based on Adhesive Type and Bonding Plane Orientation.

| SV | df | SS | MS | F-calc | F-Table | |
|---|---|---|---|---|---|---|
| | | | | | 0,05 | 0,01 |
| A (Adhesives) | 2 | 198,04 | 99,02 | 54,21** | 3,11 | 4,87 |
| B (Bonding Plane) | 1 | 156,65 | 156,65 | 85,77** | 3,95 | 6,95 |
| AB (Interaction) | 2 | 285,24 | 142,62 | 78,08** | 3,11 | 4,87 |
| Error | 84 | 153,42 | 1,83 | - | - | - |
| Total | 89 | 793,35 | - | - | - | - |

Note : ** = Highly Significant at the 99% Confidence Level

Table 6. LSD Test of Adhesive Type (A) on Bond Shear Strength.

| Adhesive Type (A) | Mean (N/mm²) | Adhesive Type | | | LSD | |
|---|---|---|---|---|---|---|
| | | $a_1$ | $a_2$ | $a_3$ | 0,05 | 0,01 |
| PVAc ($a_1$) | 5,70 | - | 0,49 ns | 3,36** | 0,57 | 0,75 |
| Epoxy ($a_2$) | 5,20 | - | - | 2,87** | | |
| Polyester ($a_3$) | 2,33 | - | - | - | | |

Note : ** = Highly Significant at the 99% Confidence Level
ns = Non Significant

Table 7. LSD Test of Bonding Plane Orientation (B) on Bond Shear Strength.

| Bonding Plane (B) | Mean (N/mm²) | Bonding Plane | | LSD | |
|---|---|---|---|---|---|
| | | $b_1$ | $b_2$ | 0,05 | 0,01 |
| R-R ($b_1$) | 3,09 | - | 2,64** | 0,69 | 0,92 |
| T-T ($b_2$) | 5,73 | - | - | | |

Note : ** = Highly Significant at the 99% Confidence Level

Table 8. LSD Test of the Interaction Between Adhesive Type and Bonding-Plane Orientation (AB) on Bond Shear Strength.

| Interaction (AB) | Mean (N/mm²) | $a_1b_1$ | $a_1b_2$ | $a_2b_1$ | $a_2b_2$ | $a_3b_1$ | $a_3b_2$ | 0,05 | 0,01 |
|---|---|---|---|---|---|---|---|---|---|
| $a_1b_1$ | 1,87 | - | - | - | - | - | - | 0,98 | 1,30 |
| $a_1b_2$ | 9,52 | 7,65** | - | - | - | - | - | | |
| $a_2b_1$ | 4,92 | 3,05** | 4,60** | - | - | - | - | | |
| $a_2b_2$ | 5,48 | 3,61** | 4,04** | 0,57 ns | - | - | - | | |
| $a_3b_1$ | 2,48 | 0,61 ns | 7,04** | 2,44** | 3,00** | - | - | | |
| $a_3b_2$ | 2,18 | 0,31 ns | 7,34** | 2,74** | 3,30** | 0,30 ns | - | | |

Note : ** = Highly Significant at the 99% Confidence Level
ns = Non Significant

Table 4 shows that the mean bond shear strength of sungkai glulam based on adhesive type (A) was highest for PVAc adhesive (a1) at 5.70 N/mm², followed by epoxy adhesive (a2) at 5.20 N/mm², and lowest for polyester adhesive (a3) at 2.33 N/mm². The ANOVA results presented in Table 5 also showed that adhesive type (A) used in the manufacture of sungkai glulam had a highly significant effect on bond shear strength. The LSD test results in Table 6 showed highly significant differences between a1 and a3 and between a2 and a3, whereas no significant difference was observed between a1 and a2. These results indicate that PVAc adhesive produced the highest bond shear strength, whereas polyester adhesive produced the lowest bond shear strength.

The bond shear strength of glulam is influenced not only by the characteristics of the wood raw material but also by the selection of adhesive type. (Hakim, 2003) reported similar findings in laminated bamboo bonded with PVAc and epoxy adhesives, where the bond shear strength obtained with PVAc was higher than that obtained with epoxy. In the present study, the bond shear strength of PVAc was also higher than that of epoxy; however, the difference was not statistically significant. Although polyester is a versatile adhesive, it is rarely used for manufacturing glulam. Bogner et al., (2001) reported in their preliminary study that standard polyester adhesive exhibited poor bonding to lignocellulosic fibers, resulting in low bond shear strength when used as an adhesive for wood composite panels.

Bond shear strength based on bonding-plane orientation showed that the tangential–tangential bonding-plane orientation (b2) had a higher mean value (5.73 N/mm²) than the radial–radial orientation (b1), which yielded 3.09 N/mm². The ANOVA results showed that bonding-plane orientation (B) had a highly significant effect on bond shear strength. Similarly, the LSD test indicated a highly significant difference between bonding in the tangential and radial planes. These findings are consistent with the results reported by Nurrachmania et al., (2020) and Wibisono, (2004), who found that bond shear strength was higher for the tangential plane than for the radial plane. This difference is attributed to the different orientations of the wood tissues in the radial and tangential planes. In the tangential plane, the ray parenchyma cells are oriented perpendicular to the bonding surface, resulting in more open cell lumens and allowing more effective adhesive penetration.

The interaction between adhesive type and bonding-plane orientation (AB) showed that the highest bond shear strength was obtained for treatment a1b2 (PVAc, T–T), whereas the lowest was observed for treatment a1b1 (PVAc, R–R). The ANOVA results showed that the interaction between adhesive type and bonding-plane orientation (AB) had a highly significant effect on bond shear strength. The LSD test indicated highly significant differences among nearly all treatment combinations, except for a2b2 versus a2b1, a3b1 and a3b2 versus a1b1, and a3b2 versus a3b1. These results are attributable to the substantially better bond shear strength provided by PVAc and epoxy adhesives compared with polyester adhesive. When compared with the standard requirements of BS EN 14080:2013 (>4.8 N/mm²) and JAS 234:2007 (5.4 N/mm²), PVAc and epoxy adhesives met the specified requirements, whereas polyester adhesive failed to meet the requirements for either bonding-plane orientation. This may be attributed to the rapid absorption of polyester adhesive into porous materials such as wood, resulting in a thin bond line (Li et al., 2017). Poor wood raw-material quality and the use of an adhesive with inadequate bonding performance may also limit adhesive penetration, resulting in lower bond strength (Rofii et al., 2022). The thin bond line produced by the polyester adhesive may have resulted in gaps at the bonding interface and weak bonding between the wood laminations in the sungkai glulam, as shown in the following figure:



Figure 2. Thin Bond Line in Polyester Adhesive Bonding Specimens.

The relatively low bond shear strength of PVAc on the radial bonding plane (a1b1) may be attributed to differences in adhesive consistency and molecular characteristics. PVAc is a thick paste with relatively larger polymer molecules than epoxy, which is applied as a viscous resin, and polyester, which is a more fluid liquid adhesive. The lower porosity of the radial plane compared with the tangential plane may restrict the penetration of PVAc molecules into the wood, resulting in relatively shallow adhesive penetration.

**Percentage of Wood Failure**

In addition to bond shear strength testing, the quality of an adhesive bond can also be evaluated based on the extent of wood failure at the bonding interface. The percentage of wood failure (%WF) provides an additional indicator of bonding quality, with a higher percentage of wood failure at the bonding interface generally indicating better bond quality. A high percentage of wood

failure indicates that the strength of the bond line is greater than that of the wood itself (Utomo & Dayadi, 2023).

The percentage of wood failure at the bonding interface based on adhesive type (A) and bonding-plane orientation (B) is presented in the following figure:

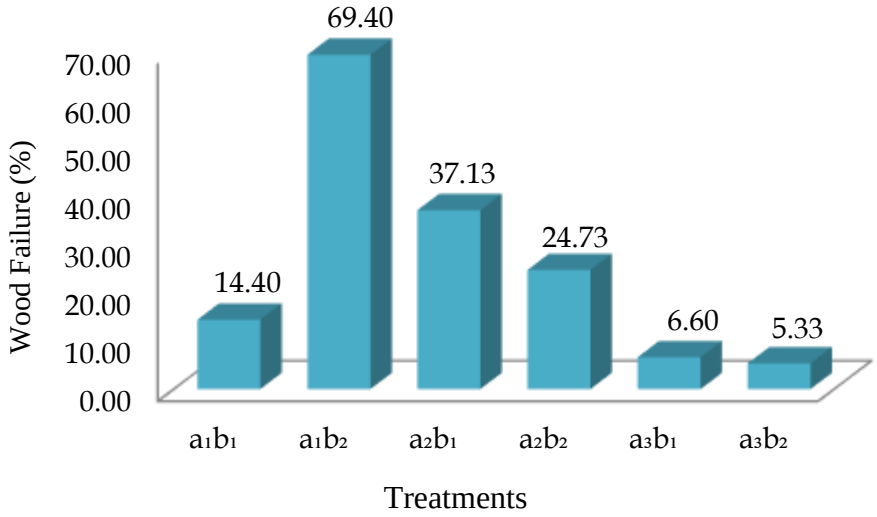



Figure 3. Mean Percentage of Wood Failure (%WF)

The highest percentage of wood failure (%WF) was observed for treatment a1b2, at 69.40%, whereas the lowest was recorded for treatment a3b2, at 5.33%. A relatively similar trend was observed between %WF and bond shear strength, with higher %WF generally corresponding to higher bond shear strength. The thin bond line produced by polyester adhesive, resulting from excessive adhesive penetration, may have weakened the adhesive bond and consequently reduced the %WF. In contrast, the relatively optimal penetration of PVAc and epoxy adhesives resulted in higher %WF values. According to the JAS 234:2007 requirement of >70% wood failure, none of the treatments fully met the specified criterion. Treatment a1b2, with a %WF of 69.40%, was the closest to the required value, whereas all other treatments were substantially below the standard requirement.

## CONCLUSIONS AND RECOMMENDATIONS

PVAc adhesive produced higher bond shear strength and percentage of wood failure (%WF) than epoxy and polyester adhesives.

The tangential–tangential bonding-plane orientation resulted in higher bond shear strength than the radial–radial bonding-plane orientation.

The highest bond shear strength and percentage of wood failure (%WF) were obtained from the interaction between PVAc adhesive and the tangential–tangential (T–T) bonding-plane orientation.

Sungkai wood bonded with PVAc adhesive using the tangential–tangential (T–T) bonding-plane orientation can be used as glulam for light structural applications because it meets the requirements of BS EN 14080:2013 and JAS 234:2007.

## FURTHER STUDY

Further research is recommended using different pressing pressures, pressing times, and adhesive spread rates.

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## REFERENCES

British Standards European Norm. 2013. BS EN 14080:2013. Glued Laminated Timber and Glued Solid Timber. Swedish Standards Institute.

Bogner, B., Dagher, H., & O'Neill, S. (2001, October 3). Bonding E-glass to Wood Using a Modified Polyester Resin. Conference: Composite Fabricators Association.

Cahyono, T. D., Wahyud, I., Priadi, T., Febrianto, F., & Ohorella, S. (2017). Sudut Kontak dan Keterbasahan Dinamis Kayu Samama pada Berbagai Pengerjaan Kayu. Jurnal Teknik Sipil ITB, 4(3), 209–216.

Dayacipta. (2022). Mengenal Kayu Sungkai dan Keunggulannya. https://dayacipta.co.id/dnews/44/mengenal-kayu-sungkai-dan-keunggulannya.html

Dumanauw, J. F. (2007). Mengenal kayu (6th ed.). Penerbit Kanisius. Jakarta.

Hakim, A. R. (2003). Pengaruh Sambungan Terhadap Sifat Mekanis Laminasi Bambu Lengkung Untuk Tujuan Penggunaan. Institut Pertanian Bogor (IPB), Bogor.

Japanese Agricultural Standard. 2007. JAS 234:2007. Japanese Agricultural Standard for Glued Laminated Timber. Notification No. 1152, September 25, 2007, Ministry of Agriculture, Forestry and Fisheries. Japan.

Kementerian LHK. (2020). Vademecum Kehutanan Indonesia 2020. Kementerian Lingkungan Hidup dan Kehutanan.

Li, R., Lan, C., Wu, Z., Huang, T., Chen, X., Liao, Y., Ye, L., Lin, X., Yang, Y., Zheng, Y., Xie, Y., & Zhuang, Q. (2017). A novel particleboard using unsaturated polyester resin as a formaldehyde-free adhesive. Construction and Building Materials, 148, 781–788. https://doi.org/10.1016/j.conbuildmat.2017.04.203

Nurrachmania, M., Rozalina, & Sidabukke, S. (2020). Kualitas Laminasi Kayu Akasia (Accacia mangium) Menggunakan Perekat Isosianat. Menara Ilmu, 14(2), 57–67.

Pujianto, B. (2023). Analisa Kekuatan Tarik Kayu Akasia Dan Sungkai Sebagai Material Kayu Alternatif Pada Lambung Kapal Kayu Tradisional. Jurnal Rekayasa Mesin, 14(1), 1–9. https://doi.org/10.21776/jrm.v14i1.656

Putra, W. W. (2025). Perbedaan Antara Resin Epoxy Dengan Resin Polyester. Binus University. Jakarta.

Rofii, M., Prasetyo, V., Listyanto, T., Primaningtyas, A., Suranto, Y., Prayitno, T., & Widyorini, R. (2022). Sifat Papan Laminasi Kayu Randu (Ceiba pentandra

(L.) Gaertn) dengan Variasi Pola Gergajian Lamina dan Arah Lapisan. Jurnal Ilmu Kehutanan, 16, 101–107. https://doi.org/10.22146/jik.v16i1.1739

Ruhendi, S., Koroh, D. N., Syamani, F. A., Yanti, H., Nurhaida, S. S., & Sucipto, T. (2007). Analisis Perekatan Kayu. In Bogor: Fakultas Kehutanan, Institut Pertanian Bogor. Bogor.

Ryanto, M., Nurhadi, L., Nurhanifan, R., Tinambunan, V., & Belakang, L. (2020). Kajian kuat tekan beton polimer dengan menggunakan pasir pantai sebagai pengganti agregat halus dan genteng jatiwangi sebagai agregat kasar. Jurnal Techno-Socio Ekonomika, Universitas Sangga Buana YPKP, 13(2), 81–89.

Setiawan, F., Sulaeman, R., & Yoza, D. (2014). Karakteristik Kayu Lapis Dari Bahan Baku Kayu Karet (Hevea braziliensis Muell. Arg) Berdasarkan Umur Pohon. Jurnal Online Mahasiswa Fakultas Pertanian Universitas Riau, 1(1), 1–11.

Somadona, S., Sribudiani, E., & Elsa Valencia, D. (2020). Karakteristik Balok Laminasi Kayu Akasia (Acacia mangium) Dan Meranti Merah (Shorea leprosula) Berdasarkan Susunan Lamina dan Berat Labur Perekat Styrofoam. Wahana Forestra: Jurnal Kehutanan, 15(2), 53–64. https://doi.org/10.31849/forestra.v15i2.5039

Suardika, I. M. A. Y., Widyana, I. N. S., & Artana, I. W. (2023). Balok Laminasi Kombinasi Bambu Petung (Dendroclamus asper) Dan Bambu Ater (Gigantochloa atter) Sebagai Bahan Konstruksi Alternatif. 19(1).

Subuh, I. M., Yasin, I., & Sulistyorini, D. (2020). Tinjauan Kuat Lentur Balok Laminasi Mekanik Kayu Glugu dan Kayu Sengon. Jurnal Teknik Sipil, 5(2), 53–60.

Sugiman, S. (2014). Pengaruh Kadar Air Awal Kayu Jati Dan Suhu Curing Perekat Pada Kekuatan Geser Sambungan Kayu Jati (Tectona grandis) Secara Perekatan. Dinamika Teknik Mesin, 4(2), 96–102.

Supraptono, B. (2014). Perekatan Kayu, Perannya Dalam Industri Kayu (L. Y. Inayatuzzahrah (ed.); First Edit). Mulawarman University Press.

Tanubrata, M. (2015). Bahan - bahan konstruksi dalam konteks teknik sipil. Jurnal Teknik Sipil, 11(65), 132–154.

Utomo, R. B., & Dayadi, I. (2023). Pengaruh Jenis Perekat dan Pengerjaan Permukaan Bidang Rekat Terhadap Keteguhan Geser Rekat Laminasi Kayu Terap (Artocarpus elasticus Reinw. ex. Blume). Jurnal Atomik, 08(2), 71–76.

Wibisono, S. (2004). Pengaruh Jumlah Perekat Terlabur, Jenis Perekat Dan Macam Bidang Rekat Terhadap Sifat-Sifat (Kualitas) Papan Laminasi Kayu Jati. Universitas Gadjah Mada.