Perennial, 2024
Vol. 20 No. 1: 1-10
p-ISSN: 1412-7784

Available Online:
http://dx.doi.org/10.24259/perennial.v20i1.33966
e-ISSN: 2685-6859

THE SHEAR BOND AND BENDING STRENGTH OF LAMINATED WOOD FROM PINE WOOD (*Pinus merkusii* Jungh et de Vr.,) and SENGON WOOD (*Paraserianthes falcataria* (L) Nielsen) GLUED WITH MELAMINE UREA FORMALDEHYDE (MUF)

Keteguhan Rekat Geser dan Keteguhan Lengkung Statis Kayu Laminasi dari Kayu Pinus (Pinus merkusii Jungh et de Vr.) dan Kayu Sengon (Paraserianthes falcataria (L) Nielsen) Berperekat Melamins Urea Formaldehida (MUF)

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ABSTRACT

Laminated wood's strength properties are influenced by the arrangement of each layers. This research aims to determine the effect of variations in layers of laminated wood to the shear bond strength, modulus of elasticity (MoE) and modulus of rupture (MoR) of laminated wood from Pine (P) and Sengon (S) wood using melamine urea formaldehyde adhesive (MUF). Laminated wood is tested using German standards DIN (Deutsches Intitut fur Normung), JAS 234-2007 and SNI 7973-2013. The data testing from 6 layer variation treatments were analyzed of variance in a completely randomized design (CRD) with 10 replications. The highest average value of shear bond strength for laminated wood in treatment G2 (Sengon-Sengon) was 6.17 N/mm^2 which met the JAS 234-2007 standard (>5.4 N/mm^2) while treatment G3 (Pine-Sengon) was 4.04 N/mm^2 and G1 (Pine-Pine) of 2.78 N/mm^2 cannot meet the standard. The highest average MoE was at A5 (P-S-S-P-P) at 8584.27 N/mm^2 and the lowest at A3 (P-S-P) at 6210.99 N/mm^2 included quality codes E8 and E6 in the SNI 7973-2013 Standard. The highest average MoR was at A4 (P-S-S-S-P) at 73.23 N/mm^2 and the lowest at A5 (P-S-S-P-P) at 61.98 N/mm^2, all treatments included quality code E25 (>25 N/mm^2) and could meet JAS 234-2007 Standards (>36.0 N/mm^2). The laminated wood in this study based on MoR is included to the strength class III – II and located between the strength class of Pine wood (strength class II) and Sengon wood (strength class III).

Keywords: Laminated wood; Melamine formaldehide; Pine; Sengon; Variations in layers.

ABSTRAK

Kayu laminasi sifat kekuatannya sangat dipengaruhi oleh penyusunan tiap lapisannya. Penelitian ini bertujuan mengetahui pengaruh variasi lapisan kayu laminasi terhadap keteguhan rekat geser, modulus elastisitas (MoE) dan keteguhan patah (MoR) kayu laminasi dari jenis kayu Pinus (P) dan kayu Sengon (S) menggunakan perekat melamin urea formaldehid (MUF). Kayu lamina diuji menggunakan standar Jerman DIN, JAS 234-2007 dan SNI 7973-2013. Data pengujian 6 perlakuan variasi lapisan dianalisis keragaman dalam rancangan acak lengkap (RAL) dengan 10 ulangan. Rataan keteguhan rekat geser kayu lamina tertinggi pada perlakuan G2 (Sengon-Sengon) sebesar 6.17 N/mm^2 dapat memenuhi standar JAS 234-2007 (>5.4 N/mm^2) sedangkan perlakuan G3 (Pinus-Sengon) sebesar 4.04 N/mm^2 dan G1 (Pinus-Pinus) sebesar 2.78 N/mm^2 tidak dapat memenuhi standar. Rataan MoE tertinggi pada A5 (P-S-S-P-P) sebesar 8584.27 N/mm^2 dan terendah pada A3 (P-S-P) sebesar 6210.99 N/mm^2 termasuk kode mutu E8 dan E6 pada Standar SNI 7973-2013. Rataan MoR tertinggi pada A4 (P-S-S-S-P) sebesar 73.23 N/mm^2 dan terendah pada A5 (P-S-S-P-P) sebesar 61.98 N/mm^2, semua perlakuan termasuk kode mutu E25 (>25 N/mm^2) dan dapat memenuhi standar JAS 234-2007 (>36.0 N/mm^2). Kayu laminasi dalam penelitian ini berdasarkan MoR termasuk kelas kuat III – II dan terletak diantara kelas kuat kayu Pinus (kelas kuat II) dan kayu Sengon (kelas kuat III).

Kata kunci: Kayu laminasi; Melamin formaldehida; Pinus; Sengon; Variasi lapisan.

Submitted: 14 March 2024; Accepted: 23 April 2024

A. INTRODUCTION

Laminated wood can be made from different types and pieces of wood of various thicknesses and lengths so that it can be used for multiple purposes such as building construction (houses, buildings, bridges, airplane hangars), furniture, sports equipment, and other structural uses (electrical transmission towers, electrical posts) to meet strength, size and shape requirements that cannot be achieved using conventional wooden posts. Their application is sometimes combined with plywood or particle board (Utomo & Dayadi, 2023).

Laminated wood has better strength properties compared to solid wood because it is made by gluing small pieces of wood into larger-sized wood by combining different types of wood of better quality, so it is also more efficient in terms of material use in wood raw materials (Wulandari & Latifah, 2022). Laminated wood maximizes dimensions by minimizing materials so that lamination is an economical design while still meeting structural principles (Jayne and Bodig, 2003 in Risnasari et al., 2012).

Pine wood (*Pinus merkusii* Jungh et de Vr.) is often used as raw material for furniture because it has advantages in terms of relatively low price compared to other commercial woods, air dry specific gravity of 0.56, accessible craft properties, moderate expansion and shrinkage properties, smooth texture, and quite strong (strong class III) even though it is in durable class IV (less durable) (Kasmudjo, 2019). Pine wood is rarely used as raw material for laminated wood compared to Sengon wood, even though it has several similar properties. Sengon wood (*Paraserianthes falcataria* (L) Nielsen) has an air dry specific gravity ranging from 0.24 to 0.49 (0.33), strength class IV-V, and durability class IV-V (RJP Sari, 2011), widely used for housing construction as a sort of wood (boards, beams, etc.) it is also used for making crates, finish for plywood, cement wool boards, fiberboards, particle boards, matches, and firewood (Apriliani et al., 2021). Sengon is a multipurpose tree, an excellent raw material for the panel and plywood industry (Mirza et al., 2020).

The strength properties of laminated wood are greatly influenced by the wood that makes it up, the bonding (type of adhesive, gluing process), and the arrangement of each layer. The arrangement of layers in laminated wood is divided into balanced and unbalanced types of laminated wood, where the critical zone of laminated wood, which is susceptible to damage due to loading, is on the outside of the laminated board/beam so that in making laminated wood on the outer layer the type of wood which has higher strength is used. Compared to the inside of the beam, in the unbalanced type, the outside of the laminated beam, which experiences tension, must use a type of wood with higher strength than the other parts (APA, 2017). Therefore, in this study, Pine wood was used as the outer layer because it has a more potent strength class (III) than Sengon wood (III-IV) which is placed on the inner layer of laminated wood.

Pine and Sengon wood gluing into laminated wood is based on this layer variation using melamine urea formaldehyde adhesive. Melamine urea formaldehyde (MUF) is known as an adhesive that is water resistant, has better heat stability, bonding ability at lower temperatures, and better adhesive impregnation properties compared to urea-formaldehyde adhesives (Supraptono, 2014). This research aims to determine the effect of variations in layers of laminated wood on shear bond strength, modulus of elasticity (MoE), and fracture strength (MoR) of laminated wood from Pine (P) and Sengon (S) wood using melamine urea formaldehyde (MUF) adhesive. This research is expected to produce good mechanical properties of laminated wood and analyze the factors that influence the quality of laminated wood bonding from variations in layers of the two types of wood.

B. METHODS

Research Tools and Materials

The equipment used were a Hofmann KF800 circular saw machine, a Hofmann C400 planing machine, a Wolpert Lestor MPDI C Series Universal Testing Machine, a Siemplekamp press machine, a drying machine (oven), digital scales, putty knife, calipers and micrometers, computers and stationery.

The raw materials used were Pine wood (*Pinus merkusii* Jungh et de Vr.) and Sengon wood (*Paraserianthes falcataria* (L) Nielsen) obtained from the Komplek Perumahan Dosen Unmul Sidomulyo Jl. Rumbia, Samarinda. The adhesive used was Melamine Urea Formaldehyde (MUF) with a mixture of Ammonium Chloride (NH_4Cl) hardener obtained from the laminate wood industry, PT Cahaya Samtraco Utama (PT. CSU), Jl. Ekonomi, Kecamatan Loa Buah, Samarinda.

Research Procedures

1. Material Preparation

Cutting a log of Pine wood (diameter of 35 cm, trunk height of ± 20 m) and Sengon wood (diameter of 60 cm, height free of branches of ± 25 m) into three parts to represent the base, middle, and top parts each 1.5 m in long (so that the entire trunk got the same opportunity to be a test sample) which was then split into four parts by crucifixion and cut into blocks measuring 6 cm x 6 cm x 75 cm to obtain radial and tangential planes that meet the test standards, then air-dried until the water content was around 12 – 15%.

The blocks were processed using a circular saw machine to become test samples according to DIN standards with dimensions of 2 cm x 2 cm x 2 cm as test examples for water content (KA) (DIN 52183-77) and density (DIN 52182-76), 2 cm x 2 cm x 36 cm as an example of a static bending strength test (MoE and MoR) (DIN 52186-78), 5 cm x 5 cm x 5 cm as an example of a shear bond strength test (DIN 52187-79). For laminated wood, boards were made with a length of 75 cm and a width of 5 cm, while the thicknesses were 0.40 cm (5-ply laminated wood), 0.67 cm (3-ply laminated wood), and 1 cm (2-ply laminated wood) (Figure 1). All materials were stored in a constant room at a temperature of 20 ± 1°C and a relative humidity of 65 ± 3 % until they reached an average equilibrium water content (according to DIN standards of ± 12%).

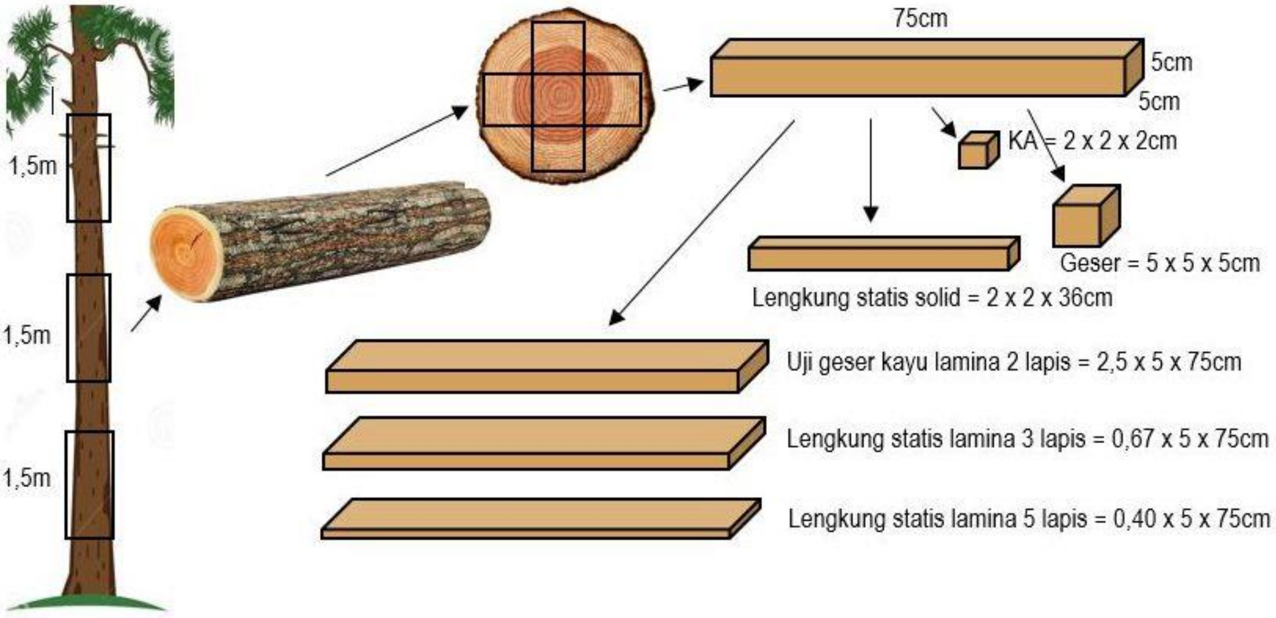

Figure 1. Cutting wood raw materials for making solid wood and laminate wood test samples

2. Making Test Samples

After the wood reached equilibrium in constant space (average moisture content ± 12 %), it was ready for the gluing process to become laminated wood following recommendations from PT. CSU. MUF adhesive and NH_4Cl hardener were mixed with a ratio of 2:1. Then the adhesive was spread using a putty knife on the two surface areas of the glued board (*double-sided glue spreading)* with a coating weight of 200 g/m^2 (0.02 g/cm^2), the section glued was a tangential plane. Before gluing, the board's surface is planed until smooth using a planing machine and cleaned of dirt.

The boards that have been whitewashed with adhesive were combined into balanced and unbalanced types of laminated wood for testing static bending strength (MoE and MoR), where Pine wood (P) is used as the outer layer because it has better strength, density, and specific gravity class than wood. Sengon (S) so that 6 (six) variations of laminated wood layers were made.

The pressing process of gluing laminated wood with MUF was carried out at room temperature with a compression pressure of 8 bar for 45 minutes, according to recommendations from PT. CSU (Saparudin, 2010). After the gluing and pressing process, the laminate board was conditioned by storing it at room temperature for seven days. Hence, the water content reaches equilibrium, and the adhesive hardens appropriately. The laminate board was then cut into pieces for static bending strength test (MoE) and MoR) measuring 2 cm x 2 cm x 36 cm, and shear bond strength test samples measuring 5 cm x 5 cm x 5 cm (Figure 2). Then, all the test samples were put into the chamber so that normal water content equilibrium could be achieved again as a condition for testing physical and mechanical properties following DIN standards.

3. Testing the Physical Properties of Laminated Wood

Tests for water content (DIN 52183-7) and density (DIN 52182-76) were carried out on solid Pine and Sengon wood test samples as controls, as well as on laminated wood from each treatment in static bending strength tests (A1, A2, A3, A4, A5, A6) to determine the effect of different treatment variations in laminated wood layers. The test samples were weighed at the average weight (B1) and measured at regular dimensions (V1), then placed in an oven at a temperature of

103 ± 2°C for 48 hours until oven-dry conditions were reached, then weighed (B0) and measured again at dimensions (V0). Regular water content and density values (normal dry and kiln dry) use the following formula:

$$KA\ (\%) = \frac{(B1\text{-}B0)}{B0} \times 100 \qquad (1)$$

$$\rho = \frac{B}{V}\ (g/cm^3) \qquad (2)$$

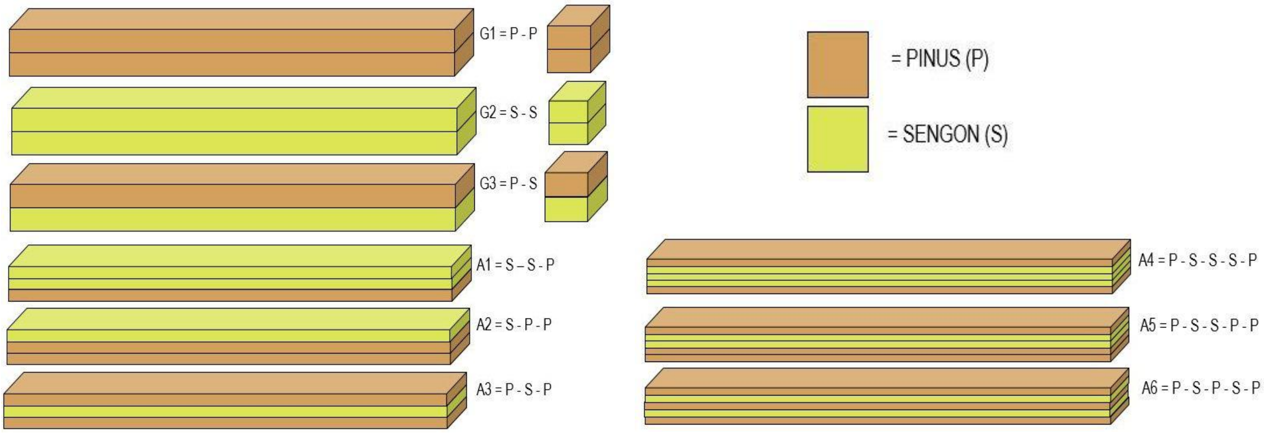

Figure 2. Making laminated wood for examples of shear bond strength test (G) and static bending test (A)

4. Testing of the Mechanical Properties of Laminated Wood

Mechanical properties were tested using shear bond and static bend strength tests (MoE and MoR). In the shear bond strength test, a test sample was made, which was a combination of the two types of wood used (PP, PS, and SS) to see the internal bonding interaction (adhesion and cohesion), which helped see the compatibility between the adhesive and the bonded material (wood) which is indicated by the shear bond strength value. In contrast, the static bending test, although it shows the adhesive strength properties, is influenced by the presence of layers of wood and the unequal load distribution at the edges and inside the wood. Burhanuddin et al., (2016) state that adhesive bond strength is a parameter of the load capacity that occurs in an adhesive bond which is located in the contact area between the wood surface and the adhesive, which is influenced by the adhesive factor and the adhesive factor.

Mechanical properties were tested using a Universal Testing Machine-Wolpert Lestor MPDI C Series test machine made in Germany in 1985. Shear strength testing (DIN 52187-79) was carried out on solid Pine (P) and Sengon (S) wood test samples as a control as well as on test samples of 2 (two) ply laminated wood with 3 (three) types of layer variation treatments (G1, G2, G3) to determine the effect of the combination of wood types on the strength of the adhesive. The value of the shear strength of solid wood and shear bond strength can be determined from the maximum load (F max) on the area of the shear area or the area of the bond area (A) using the following formula:

$$\tau = \frac{F\ maks}{A}\ \left(\frac{N}{mm^2}\right) \qquad (3)$$

Static bending strength testing (Modulus of Elasticity (MoE), and Modulus of Fracture (MoR)) (standard DIN 52186-78) was carried out on solid test samples of Pine (P) and Sengon (S) as controls as well as on test samples of 3 (three) laminated wood) and (five) layers with 6 (six) types of layer variation treatments (A1, A2, A3, A4, A5, A6) to determine the effect of treatment on stiffness (elasticity) and maximum strength in bearing loads. The MoE and MoRs can be determined from the following formula:

$$MoE = \frac{lo^3.\Delta F}{4.a^3.b.\Delta f}\left(\frac{N}{mm^2}\right) \qquad (4)$$

$$MoR = \frac{3.Fmaks.lo}{2.b.a^2}\left(\frac{N}{mm^2}\right) \qquad (5)$$

Where:
Lo = support distance (mm)
ΔF = load in the elastic region (N)
Δf = amount of deflection (mm)

a = thickness of the test sample (mm)
b = width of test sample (mm)

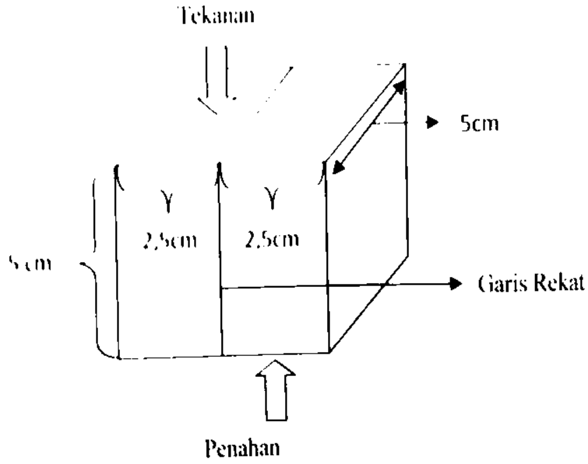

Figure 3. Shear bond strength testing

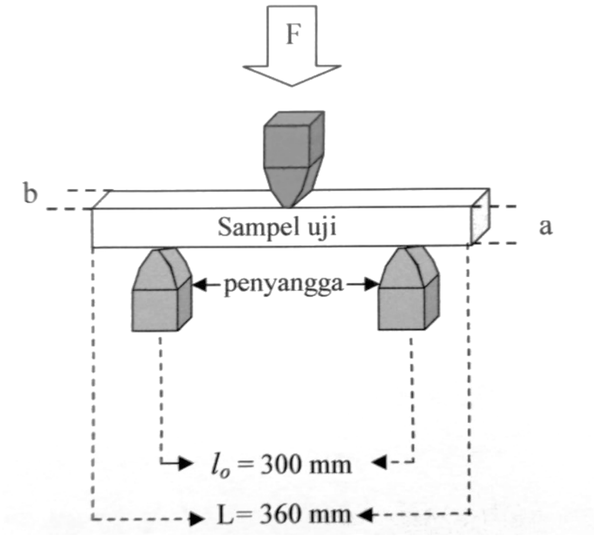

Figure 4. Static bend strength testing

Data Analysis

The data analysis used was an analysis of variance (ANOVA) in a simple completely randomized design (CRD) to determine the effect of layer variation treatment at the 95% and 99% confidence levels in the kiln dry density test, shear bond strength test, and bend strength test laminated wood, each with ten replications.

The static curve strength test consists of 6 (six) types of layer variation treatments (from top to bottom), as follows:
A1 = 3 layers (Sengon–Sengon–c / SSP)
A2 = 3 layers (Sengon–Pine–Pine / SPP)
A3 = 3 layers (Pine–Sengon–Pine / PSP)
A4 = 5 layers (Pine–Sengon-Sengon-Sengon–Pine / PSSSP)
A5 = 5 layers (Pine–Sengon-Sengon–Pine–Pine / PSSPP)
A6 = 5 layers (Pine–Sengon–Pine–Sengon–Pine / PSPSP)

The shear bond strength test consists of 3 (three) layer variation treatments, as follows:
G1 = Pine–Pine (PP)
G2 = Sengon–Sengon (SS)
G3 = Pine–Sengon (PS)

C. RESULTS AND DISCUSSION

Water Content and Wood Density

The average test values for regular water content and wood density (normal and kiln dry) can be seen in Table 1.

Table 1. Average values and coefficient of variation (KV) tests for regular water content, average density, and kiln dry density of solid wood and laminated wood

Treatment	Normal Water Content		Average Density		Furnace Dry Density	
	Average (%)	KV (%)	Average (g/cm^3)	KV (%)	Average (g/cm^3)	KV (%)
Pine (P)	11.55	5.11	0.614	3.83	0.585	4.07
Sengon (S)	11.40	4.97	0.477	5.67	0.452	6.00
A1 (SSP)	11.63	6.46	0.613	10.05	0.576	10.11
A2 (SPP)	11.47	5.03	0.665	4.62	0.624	4.65
A3 (PSP)	11.62	4.14	0.643	5.25	0.604	5.30
A4 (PSSSP)	11.17	5.92	0.569	2.44	0.535	2.90
A5 (PSSPP)	11.47	5.03	0.664	4.76	0.629	4.97
A6 (PSPSP)	11.54	6.21	0.619	7.97	0.586	7.68

The average value of regular water content of solid wood and laminated wood from Pine and Sengon wood species at the time of testing was relatively low and uniform, ranging from 11.17% - 11.63%, indicating that the conditioning had reached equilibrium in a constant space and had met the requirements in DIN standard is ±12%. The uniformity of regular water content is also indicated by the low and uniform average value of the coefficient of variation (KV), ranging from 4.14% – 6.46%. A low and uniform water content with a low and uniform KV value indicates that the water content has been controlled, and the difference in water content values for solid wood and laminated wood, which can affect the test values for shear bond and static bending strength, could be ignored. According to (Somadona et al., 2020), one of the factors that influences the quality of bonding is the water content of the wood. Wood's high water content will inhibit the adhesive liquid's bonding (Nurrachmania & Sidabukke, 2020). The high water content will also reduce adhesion properties and cause increased wood absorption and the bond to weaken (Haygreen and Bowyer, 1996 in Utomo & Dayadi, (2023). The water content in this study met the JAS 234-2007 standard (JAS, 2007), which requires a test water content of around 12%.

The average density of Pine wood is 0.614 g/cm^3 while the kiln dry density is 0.585 g/cm^3, which means that Pine wood is included in the light (<0.6) to medium (0.6 – 0.75) wood group. Sengon's average and kiln-dry density are 0.477 g/cm^3 and 0.452 g/cm^3, respectively, which means it is included in the light wood group (PIKA, 2003). Laminated wood from the research treatment, which was made based on variations in Pine and Sengon wood layers, showed the lowest average density in the A4 treatment of 0.569 g/cm^3 and the highest in the A2 treatment of 0.665 g/cm^3. In comparison, the lowest dry kiln density in the A4 treatment was 0.535 g/cm^3, and the highest in treatment A5 was 0.629 g/cm^3. The kiln dry density values of laminated wood in treatments A2, A3, A5, and A6 also tend to be higher than the kiln dry densities of solid Pine and Sengon wood, except in treatments A1 and A4, where the values are between the density values of Pine and Sengon wood. This phenomenon is caused by the layer variation treatment, where the laminated wood layer is dominated by Sengon wood, so that the density value will be lower. To see the effect of layer variations on the dry density of laminated wood kilns, see the table below.

Table 2. ANOVA of dry density of laminate wood furnace based on layer variations

Sources of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Count	F Table	
					0.05	0.01
Treatment	0.060	5	0.012	8.515**	2.386	3.377
Error	0.076	54	0.001	-	-	-
Total	0.136	59	-	-	-	-

Note: ** = very significant effect at the 99% confidence level.

Variation analysis shows that the layer variation treatment significantly affects the dry density of laminated wood kilns. The difference in the kiln dry density value is caused by the composition of the types of wood that make up the laminated wood, where the more kinds of Pine wood that have a higher density than the Sengon wood type in the laminated wood, the tendency is for the density value of the laminated wood to be higher. Differences in the density of laminated wood can also be caused by differences in the number of layers of wood where the adhesive is applied according to the weight of the laminated wood in the adhesive area in making laminated wood. Bowyer et al., (2003) in Somadona et al., (2020) state that differences in laminated wood density values are influenced by the type of wood that makes it up, cell wall thickness, water content, and the gluing process.

Shear Strength, Modulus of Elasticity (MoE), and Modulus of Fracture (MoR)

Tests for shear strength and static bend strength (MoE and MoR) were carried out on solid Pine and Sengon wood as controls and laminated wood. The average test values for the mechanical properties of laminated wood can be seen in the table below.

Table 3. Average test values for shear strength, MoE, and MoR for solid and laminated wood

Treatment	Shear Strength (N/mm^2)	MoE (N/mm^2)	MoR (N/mm^2)
Pine (P)	12.08	13414.68	96.72
Sengon (S)	9.09	8676.76	68.90
G1 (PP)	2.78	-	-
G2 (SS)	6.17	-	-
G3 (PS)	4.04	-	-
A1 (SSP)	-	8442.88	70.63
A2 (SPP)	-	6242.96	71.91
A3 (PSP)	-	6210.99	72.39
A4 (PSSSP)	-	8179.33	73.24
A5 (PSSPP)	-	8584.27	61.98
A6 (PSPSP)	-	8072.70	66.37

Note: G = Shear bond strength test of laminated wood; A = Static bending strength test of laminated wood (MoE and MoR).

An ANOVA was carried out to determine the effect of treating a combination of gluing 2 (two) types of wood (Pine and Sengon) on the shear bond strength value, which can be seen in the table below.

Table 4. ANOVA shear bond strength of laminated wood

Sources of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Count	F Table	
					0.05	0.01
Treatment	58,948	2	29,474	10.308**	3.354	5.488
Error	77,195	27	2,859	-	-	-
Total	136,144	29	-	-	-	-

Note: ** = very significant effect at the 99% confidence level.

Table 3 shows that the average value of the laminated wood shear bond strength test is lower than that for solid Pine and Sengon wood. In contrast, laminated wood's shear bond strength test is highest in the G2 treatment at 6.17 N/mm^2, followed by G3 at 4.04 N/mm^2, and the lowest in G1 was 2.78 N/mm^2. Table 4 shows that the combination treatment of gluing Pine and Sengon wood species significantly affects the strength of laminated wood's shear bond. It may occur due to differences in the anatomical and chemical properties of the type of wood used. Even though the strength and density class values for Pine wood are higher than Sengon wood, the anatomical structure and chemical content are different. The tendency shows that the MUF bonding quality is not good when gluing laminated wood using Pine wood. Pine wood is a type of needle leaf wood that primarily consists of tracheids (90 - 95%) and does not have pores (vascular tissue). Pine wood also has low cell wall porosity and permeability (Karlinasari et al., 2010). Pine wood also contains higher extractive substances than Sengon wood. Pari et al., (2006) examined the chemical components of 10 types of wood plants and stated that Pine wood, based on the classification of chemical elements according to the Department of Agriculture (1976), was included in the medium class (2 - 4%), while Sengon wood was included in the low class (< 2%). The type of adhesive, low porosity, and permeability, as well as a higher content of extractive substances in Pine wood, can interfere with bonding, causing the penetration and hardening of the laminated wood adhesive in combination with Pine wood (G1 and G3) to be not optimal so that the shear bond strength value tends to be lower compared to G2 (Sengon-Sengon) laminated wood. Santoso & Malik (2005), in their research on the influence of the type of adhesive (LRF, TRF, PRF) and the combination of wood types (Pine, Damar, and Gmelina) stated that in the dry state, the type of adhesive and the combination of wood types have a very significant effect on adhesive strength. sliding laminated wood, where research results on the combination treatment of K1 wood species (Pine-Pine-Pine) also showed low adhesive strength at 8 hours and 15 hours of compression and from the three types of adhesive used.

The shear bond strength value of laminated wood in this study was only treated G2 (Sengon-Sengon) at 6.17 N/mm^2, which could meet the JAS 234-2007 (JAS, 2007) standard at 5.4 N/mm^2, while G1 (Pine-Pine) of 2.78 N/mm^2 and G3 (Pine-Sengon) of 4.04 N/mm^2 cannot meet the standard.

The MoE is obtained under loading conditions where the wood being tested has not yet experienced damage (elastic area). In contrast, the MoR is obtained when the wood being tested for loading has begun to experience damage (plastic area). The average value of the MoE test in Table 3 shows that the highest MoE for laminated wood in treatment A5 is 8584.27 N/mm^2, and the lowest in A3 is 6210.99 N/mm^2. The range of MoE for laminated wood is also lower compared to the MoE of Pine solid wood 13414.68 N/mm^2 and Sengon 8676.76 N/mm^2. Analysis of variance (ANOVA) of MoE in Table 5 shows that the treatment of variations in laminated wood layers significantly influences the MoE.

Table 5. ANOVA of MoE based on variations in laminated wood layers

Sources of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Count	F Table	
					0.05	0.01
Treatment	60,062,456,197	5	12,012,491,239	9,790**	2.386	3.377
Error	66,258,555,587	54	1,227,010,289	-	-	-
Total	126,321,011,784	59	-	-	-	-

Note: ** = very significant effect at the 99% confidence level.

Table 6. ANOVA of MoR based on variations in laminated wood layers

Sources of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Count	F Table	
					0.05	0.01
Treatment	957,263	5	191.452	1.415ns	2.386	3.377
Error	7,302,139	54	135.224	-	-	-
Total	8,259,403	59	-	-	-	-

Note: ns = has no significant effect.

The data in Table 3 also shows a tendency for the MoE of laminated wood to be low when the layers are bonded with pine wood and with the increasing number of layers of pine wood glued with MUF adhesive. These MoE (A2, A3, A6) follow the shear bond strength test results in this study, which shows that gluing MUF with Pine wood will provide a lower bond strength value. In their research, Sinaga & Hadjib (1989) also found that laminated wood with Pine wood components had low MoE and MoRs. This phenomenon is because Pine wood is a type of needle wood that does not have pore cells (vessels), so adhesive penetration is less than perfect and uneven, as well as a higher content of extractive substances than Sengon wood, which can interfere with bonding.

The MoE of 5-ply laminated wood (A4, A5, A6) ranges from 8072.70 – 8584.27 N/mm^2 which tends to be higher than 3-ply laminated wood (A1, A2, A3) which ranges from 6210.99 – 8442.88 N/mm^2. The results of this research follow the research by Sari & Praja, (2006), which examined the influence of connections and the number of layers of Red Meranti laminate wood, as well as research by Purwaningrum et al., (2019) which examined the influence of the number of layers in Red Meranti and Galam laminate wood, which concluded that laminated wood with a greater number of layers tends to produce a better MoE.

The MoE of laminated wood ranges from 6210.99 N/mm^2 - 8584.27 N/mm^2 including quality code E6 (6000 N/mm^2) – E8 (8000 N/mm^2) which is lower than solid pine wood (13414.68 N/mm^2) quality code E13 (13000 N/mm^2) and Sengon solid wood (8676.76 N/mm^2) quality code E8 (8000 N/mm^2) in the SNI 7973-2013 standard (BSN, 2013). Based on the JAS 234-2007 standard (JAS, 2007), only treatments A1, A4, A5, and A6 met the standard >8000 N/mm^2.

ANOVA of MoR in Table 6 shows no significant effect of varying treatments of laminated wood layers on the MoR because the average value of MoR in all treatments is almost the same. The average MoR in Table 3 shows that the highest MoR for laminated wood in the A4 treatment was 73.24 N/mm^2, and the lowest in A5 was 61.98 N/mm^2. The range of MoRs for laminated wood A1, A2, A3, and A4 also has a similar tendency to the MoE, namely lower than the MoR for solid pine wood, 96.72 N/mm^2.

In A5 and A6, the MoR is slightly lower than the MoR for Sengon solid wood, 68.90 N/mm^2, due to the layer arrangement and number of layers. Treatment A5, which uses Pine wood in the critical zone (top and bottom), especially in the bottom part, which experiences tensile forces, consists of a Pine-Pine wood structure that in the shear bond strength test shows low bond strength, which is the cause of the low in MoR. In the A6 treatment, pine wood is used between the layers, the bonding quality of which is low, causing the MoR to be low. Sinaga & Hadjib, (1989) stated that in laminated wood construction, a combination of 2 to 5 layers and adhesive as a binding component is possible, and there are the weakest and strongest components that can affect laminated wood.

Referring to the classification of wood strength classes according to Oey (1990) in the Ministry of Environment and Forestry (2020), the MoR of laminated wood in this study ranges from 61.98 N/mm^2 - 73.24 N/mm^2, where treatments A1, A5, A6 belong to strength class III (49 – 71 N/mm^2), treatments A2, A3, and A4 belong to strength class II (71 – 102 N/mm^2). In contrast, The MoR of Pine solid wood is class II, and Sengon solid wood is class III. The MoR of all treatments in this study includes the quality code E25 (>26.0 N/mm^2) in the SNI 7973-2013 standard (BSN, 2013), and all treatments met the JAS 234-2007 standard (>36.0 N/ mm^2).

D. CONCLUSIONS

1. The average value of regular water content of solid wood and laminated wood from Pine and Sengon wood types at the time of testing ranged from 11.17% – 11.63% with a coefficient of variation (KV) ranging from 4.14% – 6.46%, the value of This normal water is uniform and meets the JAS 234-2007 standard which requires a test water content of around 12%.
2. The average and dry kiln density of Pine wood is each 0.614 g/cm^3 and 0.585 g/cm^3, which means that pine wood is included in the light (<0.6) to medium (0.6 – 0.75) wood group, while the density of regular and kiln-dried Sengon wood is 0.477 g/cm^3 and 0.452 g/cm^3, respectively, included in the light wood group. The average density of laminated wood ranges from 0.569 – 0.665 g/cm^3 and kiln dried ranges from 0.535 – 0.629 g/cm3, where the dry density of A2, A3, A5, A6 kilns is higher than the kiln dry density of Pine and Sengon solid wood which is influenced by the composition of the wood species, the number of layers and the weight of the adhesive coating on the laminated wood.
3. The highest shear bond strength of laminated wood in the G2 (Sengon-Sengon) treatment was 6.17 N/mm^2 which could meet the JAS 234-2007 standard (>5.4 N/mm^2) while the G3 (Pine-Sengon) treatment was 4.04 N/mm^2 and G1 (Pine-Pine) of 2.78 N/mm^2 cannot meet the standard, this value is lower than the shear strength of Pine and Sengon solid wood which is caused by differences in anatomical properties, chemical properties of wood, and less according to the type of MUF adhesive.
4. The highest MoE was in treatment A5 (8584.27 N/mm^2), including quality code E8 and the lowest was in A3 (6210.99 N/mm^2), including quality code E6 in standard SNI 7973-2013, lower than the MoE of Pine solid wood (13414.68 N/mm^2) and Sengon (8676.76 N/mm^2) which includes quality codes E13 and E8, this is caused by variations in laminated wood layers and the low bond strength of Pine wood. There is a tendency for the MoE of 5-ply laminated wood to be higher than 3-ply laminated wood. Based on the JAS 234-2007 standard, only treatments A1, A4, A5, and A6 met the standard >8000 N/mm$^{2.}$
5. The modulus of fracture (MoR) in treatments A1, A2, A3, A4 (70.63 - 73.23 N/mm^2) is lower than the MoR of solid Pine wood (96.72 N/mm$^{2)}$, while A5, A6 (61.98 – 66.37 N/mm^2) lower than the MoR of Sengon solid wood (68.90 N/mm^2), which is due to variations in layers using Pine wood with low adhesion properties in the critical zone (experiencing pressure and tension forces) especially on the bottom layer of laminated wood.
6. Based on the MoR test value, the laminated wood in this study belongs to strength class III (A1, A5, A6) to strength class II (A2, A3, A4), while solid Pine wood belongs to strength class II and Sengon solid wood is strength class III. All laminated wood treatments in this study included the quality code E25 (>26 N/mm^2) in the SNI 7973-2013 standard, and all treatments could meet the JAS 234-2007 standard (>36.0 N/mm^2).
7. The MUF bonding quality is not good (not optimal) due to the combination of using Pine wood both in the shear bond test and the MoE and MoR tests which use Pine wood in the critical zone (top and bottom), especially at the bottom which experiences tensile forces consisting of an arrangement Pine wood. The MoE of 5-ply laminated wood (A4, A5, A6) ranges from 8072.70 – 8584.27 N/mm^2 which tends to be higher than 3-ply laminated wood (A1, A2, A3) which ranges from 6210.99 – 8442.88 N/mm^2.

REFERENCES

APA. (2017). X440E - Glulam Product Guide. The Engineered Wood Association, Form No.X440E.

Apriliani, D., Fiesnanda, A., Putra, B., & Rahayu, W. W. (2021). Identifikasi Dan Inventarisasi Jenis Pohon Komersial Sebagai Investasi Jangka Panjang. February.

BSN. (2013). SNI 7973-2013 Spesifikasi Desain untuk Konstruksi Kayu. Badan Standardisasi Nasional.

Burhanuddin, V., Ulfah, D., & Emelya, R. (2016). Sifat Fisika dan Nilai Keteguhan Rekat Kayu Kecapi (Sandoricum koetjape Merr). Jurnal Hutan Tropis, 4(2), 145–153.

JAS. (2007). Japanese Agricultural Standard for Glued Laminated Timber. Japanese Agricultural Standard (JAS 234), 1152, 1–45.

Karlinasari, L., Nawawi, D., & Widyani, M. (2010). Kajian Sifat Anatomi dan Kimia Kayu Kaitannya dengan Sifat Akustik Kayu. Jurnal Ilmu-Ilmu Hayati Dan Fisik, 12(3), 110–116.

Kasmudjo. (2019). Peluang kayu mindi, pinus dan trembesi sebagai bahan mebel dan kerajinan. 182–192.

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

Mirza, H., Mahdie, M. F., Rahmat, G. A., Program, T., & Kehutanan, S. (2020). Sifat Fisik dan Mekanik Papan Partikel dari Serbuk Gergajian Kayu Sengon Laut (Paraserianthes falcataria) menggunakan Perekat PVAC Physical and Mechanical Properties of Particle Board of Sea Sengon (Paraserianthes falcataria) Wood Sawdust Using PVAC Adhes. Jurnal Sylva Scienteae, 03(5), 855–867.

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

Pari, G., Roliadi, H., Setiawan, D., & Saepuloh, S. (2006). Komponen Kimia Sepuluh Jenis Kayu Tanaman Dari Jawa Barat. Jurnal Penelitian Hasil

Hutan, 24(2), 89–101. https://doi.org/10.20886/jphh.2006.24.2.89-101

PIKA. (2003). Mengenal Sifat-Sifat Kayu Di Indonesia dan Penggunaannya (Cetakan ke). Penerbit Kanisius Yogyakarta.

Purwaningrum, T., Hamidah, S., & Yuniarti. (2019). Pengaruh Jumlah Lapisan Terhadap Sifat Fisika Mekanika Balok Laminasi Kayu Galam (Melaleuca cajuputi). Jurnal Sylva Scienteae, 2(1), 155–163.

Risnasari, I., Azhar, I., & Sitompul, A. (2012). Karakteristik Balok Laminasi Dari Batang Kelapa (Cocos Nucifera L.) Dan Kayu Kemiri (Aleurites Moluccana Wild.) (Characteristics of Glued Laminated Beams of Coconut Trunk (Cocos Nucifera L.) and Candlenut Wood (Aleurites Moluccana Wild.). Foresta, 1(2), 79–87.

Santoso, A., & Malik, J. (2005). Pengaruh Jenis Perekat dan Kombinasi Jenis Kayu Terhadap Keteguhan Rekat Kayu Lamina (pp. 375–384). Pusat Penelitian dan Pengembangan Hasil Hutan.

Saparudin. (2010). Laporan Pelaksanaan Kegiatan Praktek Kerja Lapang (Pkl) Di Pt. Cahaya Samtraco Utama Samarinda.

Sari, N. M., & Praja, E. E. (2006). Pengaruh Pola Sambungan dan Banyaknya Jumlah Lapisan terhadap Sifat Fisika dan Mekanika Papan Lamina Kayu Meranti Merah (Shorea leprosula Miq.). Jurnal Hutan Tropis Borneo, 18, 33–38.

Sari, R. J. P. (2011). Karakteristik Balok Laminasi dari Kayu Sengon (Paraserianthes falcataria (L.) Nielson), Manii (Maesopsis eminii Willd.), dan Akasia (Acacia mangium Engl.). Institut Pertanian Bogor.

Sinaga, M., & Hadjib, N. (1989). Sifat Mekanis Kayu Lamina Gabungan dari Kayu Pinus dan Kayu Eucalyptus. Duta Rimba, 15.

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

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

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.

Wulandari, F. T., & Latifah, S. (2022). Karakteristik Sifat Fisika Dan Mekanika Papan Laminasi Kayu Bayur (Pterospermum diversifolium) Sebagai Bahan Substitusi Papan Solid. Wahana Forestra: Jurnal Kehutanan, 17(2), 177–191. https://doi.org/10.31849/forestra.v17i2.9362.