Perennial, 2024
Vol. 20 No. 2: 84-90
p-ISSN: 1412-7784

Available Online:
http://dx.doi.org/10.24259/perennial.v20i2.40340
e-ISSN: 2685-6859

EFFECT OF COMPRESSION PRESSURE ON THE BENDING STRENGTH OF FINGER-JOINTED RED MERANTI (*SHOREA* SP.) GLUED WITH POLYVINYL ACETATE (PVAc)

Pengaruh Tekanan Kempa Terhadap Keteguhan Lengkung Statis pada Sambungan Menjari Kayu Meranti Merah (Shorea sp.) dengan Perekat Polivinil Asetat (PVAc)

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ABSTRACT

The joint of glued laminated wood with adhesive is widely used and affects the static bending strength value in its use. The compression pressure is one of the critical factors in the gluing of joints. This research aims to determine the effect of variations in compression pressure on the static bending strength of finger-jointed red meranti (*Shorea* sp.) wood glued with an exterior type of polyvinyl acetate (PVAc) adhesive in Synteco brand. The static bending strength testing referred to the German standard DIN (Deutsches Intitut fur Normung) DIN 52186-78. The data from 3 treatments of compressive pressure variations (2 bar, 2.5 bar, and 3 bar) were analyzed for variation in a completely randomized design (CRD) with 20 replications. The research results showed that the highest static bending strength of finger-jointed *Shorea* sp. was found at a compression pressure of 3 bar (P3), in which its modulus of elasticity (MoE) was 9,975.53 N/mm^2 and the modulus of rupture (MoR) was 60.77 N/mm^2. The MoE and MoR of the finger-jointed wood were still lower than its control (without joints), in which MoE was 10,017.07 N/mm^2 and MoR was 82.07 N/mm^2.

Keywords: compression pressure; finger joint; modulus of elasticity; modulus of rupture; red meranti

ABSTRAK

Penyambungan kayu lamina dengan perekat banyak digunakan dan mempengaruhi nilai keteguhan lengkung statis dalam penggunaannya. Tekanan kempa adalah salah satu faktor yang penting dalam perekatan sambungan. Penelitian ini bertujuan untuk mengetahui pengaruh variasi tekanan kempa terhadap keteguhan lengkung statis pada sambungan menjari kayu Meranti Merah dengan perekat polivinil asetat (PVAc) merk Synteco tipe eksterior. Pengujian keteguhan lengkung statis menggunakan standar Jerman DIN (Deutsches Intitut fur Normung) DIN 52186-78. Data pengujian dari 3 perlakuan variasi tekanan kempa (2 bar, 2,5 bar dan 3 bar) dianalisis keragaman dalam rancangan acak lengkap (RAL) dengan 20 ulangan. Hasil penelitian menunjukkan nilai rataan tertinggi keteguhan lengkung statis terdapat pada perlakuan sambungan menjari dengan tekanan kempa 3 bar (P3) yaitu modulus elastisitas (MoE) sebesar 9,975.53 N/mm^2 dan keteguhan patah (MoR) sebesar 60.77 N/mm^2. Nilai MoE dan MoR pada sambungan menjari ini masih lebih rendah daripada kontrol (tanpa sambungan) yaitu MoE sebesar 10,017.07 N/mm^2 dan MoR sebesar 82.07 N/mm^2.

Kata kunci: meranti merah; modulus elastisitas; modulus patah; sambungan menjari; tekanan kempa

Submitted: 26 September 2024; Accepted: 24 October 2024

A. INTRODUCTION

Wooden building construction often requires long timbers that are difficult to obtain in the market. So, to obtain long-sized wood, a joint must be made. A joint is a woodworking method involving two or more pieces of wood connected to obtain the desired length of timber. Many studies state that the joint is the weakest point in the material, known as the joint weakness theory (*Weibull* theory), which is described as a chain that connects to a material (Dayadi 2022).

Red Meranti (*Shorea* sp.) is a type of Indonesian commercial wood commonly used as a raw material for building construction. *Shorea* sp. is also the primary raw material used by PT Cahaya Samtraco Utama to produce lamina wood, which is sold to various countries. *Shorea* sp. has an average value of modulus of elasticity (MoE) of 4,118 N/mm^2, modulus of rupture (MoR) of 89 N/mm^2 at a moisture content of 7.37%, and a wood density of 0.45 g/cm^3 (Qolbi 2022). The manufacture of lamina wood from the *Shorea* sp. needs to be studied to determine and improve the characteristics of its physical and mechanical properties, especially as lamina wood in the form of finger joints.

Polyvinyl acetate (PVAc) is a thermoplastic adhesive widely used to adhere to plywood, blockboard, and lamina wood products. PVAc is a ready-to-use adhesive that is very easy to use, non-toxic, transparent adhesive line, odorless, non-flammable, strong, and durable adhesion properties, known as interior and exterior adhesive materials. It has a viscosity of 0.4 cP at 20°C, solubility in water of about 2% at 25°C, and a low boiling point of 72.7°C (Hanif & Rozalina 2020). PVAc is very suitable for use in the manufacture of wood lamina, where it does not require heat to compress, and the hardening of the adhesive occurs at room temperature (*cold glue*).

Many types of wood joints and tools could be used, including joints with nails, bolts, pegs, and adhesives. Asrib (2024) mentioned that the type of joint tool gives different results, where the use of adhesive in wood joint provides the best results where the weakening of the joint strength is the lowest compared to the joint tool in the form of nails, bolts, cockroaches and pegs. In addition, adhesives have several other advantages, such as being relatively faster and easier to work with. Besides that, it also produces a joint end product with a satisfactory appearance, suitable surfaces and texture, no cavities, no protruding parts such as screws and so on, easy and fast in the application, and at the same time it can connect many components, lighter material weight and uniform distribution of stress (force) on all parts of the jointed object (Handayani 2009; Monotaro 2023). The *finger joint* type also has advantages over other types of joints. Jokerst (1981) and Safitri & Gunawan (2010) mentioned that some types of joints are too challenging to make, not good in bond strength, and often ineffective and not durable. While finger joints are also the strongest because they have a multilevel inclined joint surface, the inclined fiber plane surface can adhere better, so it has greater strength than upright joints with end grain surfaces that cannot adhere well. The behavior of the type of finger-jointed wood in receiving tensile and pressure forces is very similar to the behavior of wood that has no defects in receiving tensile and pressure forces, the modulus of elasticity in the tensile force is very similar to the pressure force, and the strain at the limit of the proportion of tensile force in the fingered joint is 45% higher than the pressure force.

The compression pressure is one of the crucial factors in the gluing process, where the purpose of the compression pressure is to control the thickness of the adhesive line, as well as to make contact between the adhered surfaces while increasing the strength of the joint (Kurt & Cil 2012). Pressure also helps the entry of adhesive into the wood cells. Too low pressure causes gluing defects, known as blistering. Too thick adhesive lines and rupture of the face of the sedan press *pressure* is one of the *main* factors, while too high pressure can cause excessive penetration of the adhesive or the adhesive line is too thin (Wulandari *et al.* 2023).

This study aims to analyze the effect of compression pressure on the static bending strength of *Shorea* sp. with exterior-type PVAc adhesive. This study is expected to provide information on using compression pressure to produce the best static bending strength in finger-jointed *Shorea* sp.

B. METHODS

Materials and Tools

The manufacture of wood joints was carried out at PT Cahaya Samtraco Utama Samarinda using a finger joint molding machine and a wood joint felting machine. The manufacture of test samples and testing of physical and mechanical properties were carried out at the Forest Products Industry and Testing Laboratory, Faculty of Forestry, Mulawarman University, Samarinda, using a Hofmann KF800 circular saw, a Hofmann C400 mallet, and a Wolpert Lestor MPDI C-Series Universal Testing Machine (UTM).

The raw material was Red Meranti wood (*Shorea* sp.), which was used to make lamina wood finger joints at PT. Cahaya Samtraco Utama Samarinda from several logs. The adhesive material used was PVAc exterior type Synteco brand used by the lamina wood industry PT. Cahaya Samtraco Utama Samarinda, which PT.CSU purchased from the adhesive manufacturer of the city of Bangkok, Thailand. Storage of this adhesive is sufficient at room temperature and includes ready-to-use adhesives. According to Hanif & Rozalina (2020), Synteco PVAc is included in the European standard EN 205 category of PVAc type D4, namely PVAc, which can be used for exteriors with extreme climatic conditions and always in contact with water (swimming pools), exterior furniture, windows, and so on.

Procedures

1. Materials Preparation and Finger Joints Production

Finger-jointed boards were made by PT Cahaya Samtraco Utama Samarinda, where the raw material for *Shorea* sp. boards was dried in a drying oven at a temperature of 65°C - 85°C until the appropriate moisture content was obtained with gluing conditions (±10%) according to procedures at PT. CSU. According to Nurrachmania & Sidabukke (2020), good moisture content for gluing ranges from 6% to 14%. This was followed by splitting the board into widths of about 20 cm, cutting lengths ranging between 20 to 80 cm, and planning to get a smooth board surface. At the end of the board, finger joints were formed using a finger joint molder. The finger joint was made with a tongue length of 1 cm, with a total of 2 tongues at a width of 1 cm.

Boards that had been cleaned and smooth surfaces were then manually applied PVAc adhesive on the cross-section of the finger joints using a brush. Next, the board was connected to its partner on the conveyor machine, and then the pressure (2 bar, 2.5 bar, and 3 bar) was applied to the ends of the board for ± 3 minutes at room temperature. Applying PVAc adhesive manually using a brush, the compression pressure, compression time, and temperature were set following the usual procedures carried out by PT Cahaya Samtraco Utama Samarinda in producing its commercial lamina wood.

The boards spliced together were then conditioned for 5 days to increase the penetration of the adhesive and achieve the hardening condition of the gluing at the joints. Then, the boards were applied to the final treatment as surface grinding to obtain a finger-jointed board with a uniform thickness and smooth surfaces.

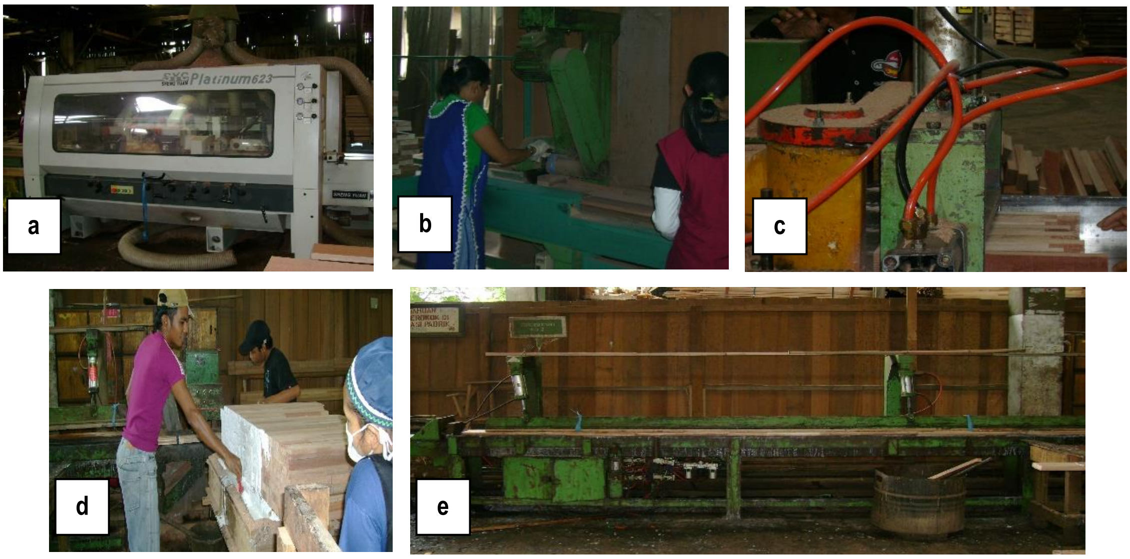

Figure 1. Finger-joint board manufacturing process: surface planning (a), cutting (b), making finger joints (c), manual application of adhesive (d), and wood joint compression (e)

2. Sample Preparation of Static Bending Strength Test

The finger-jointed boards that initially measured about 40 cm x 20 cm x 2 cm were then made into static bending strength test samples according to the German standard DIN 52186-78 measuring 36 cm x 2 cm x 2 cm using a splitting saw (ripsaw) where for each compression pressure treatment 20 replicates were made. All test samples were stored in a room at a constant temperature of 20±1°C and a relative humidity of 65±3%, following DIN standards until an equilibrium moisture content was obtained. Then, the samples were tested for physical properties (moisture content and density) and mechanical properties of static bending strength to determine the value of the MoE and MoR.

Figure 2. Static bending strength test samples (right) from a finger-jointed board (left)

3. Mechanical Properties Testing

Static bending strength tests (MoE and MoR) following the DIN 52186-78 standard were carried out on test samples of control wood (without joints) and treated wood at a compression pressure of 2 bar, 2.5 bar, and 3 bar. The MoE and MoR values can be determined from the following formulas:

$$MoE = \frac{lo^3.\Delta F}{4.a^3.b.\Delta f}$$

$$MoR = \frac{3.Fmaks.lo}{2.b.a^2}$$

Where, lo is support distance (mm), ΔF is load in the elastic region (N), Δf is the amount of deflection (mm), a is the test sample thickness (mm), and b is the width of the test sample (mm).

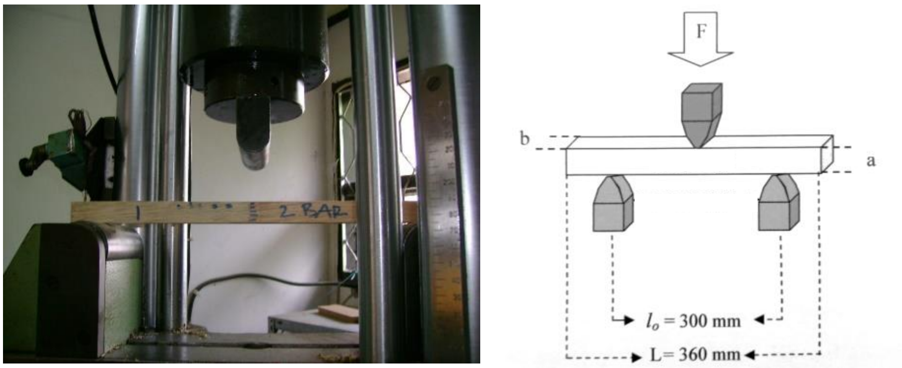

Figure 3. Static bending strength testing

Data Analysis

The data analysis used was an analysis of variance (ANOVA) in a simple completely randomized design (CRD) to determine the effect of pressure variation treatment on the value of static bending strength test (MoE and MoR) of *Shorea* sp. with finger joints. ANOVA was tested at 95% and 99% confidence levels, and each treatment was tested with as many as 20 replicates. The static bending strength test consists of three variations of compression pressure, which were 2 bar (P1), 2.5 bar (P2), and 3 bar (P3). If the F-count > F-table, the compression pressure significantly affects the static bend strength. Otherwise, if the F-count < F-table, the compression pressure does not significantly affect the static bend strength.

C. RESULTS AND DISCUSSION

Wood Moisture Content and Density

The average test values of regular moisture content and density (regular and oven-dried) of *Shorea* sp. used in this study can be seen in Table 1.

Table 1. Moisture content and wood density of red meranti wood (*Shorea* sp.)

Physical Properties of *Shorea* sp.	Average	Coefficient of Variation (%)
Regular moisture content (%)	11.01	3.87
Regular density (g/cm^3)	0.56	8.93
Oven-dried density (g/cm^3)	0.54	8.83

The average value of regular moisture content of *Shorea* sp. after being stored in a constant room at the time of testing was 11.01% with a coefficient of variation of 3.87%, indicating that the conditioning of *Shorea* sp. test samples for testing physical properties and mechanical properties has reached equilibrium moisture content in a constant room and has met the DIN standard requirements of regular moisture content of ± 12%. The diversity or variation of the test data group was indicated by the coefficient of variation, where the coefficient of variation of regular moisture content in this study was relatively low (3.87%). This indicates that the conditioning in the constant chamber is good enough that the moisture content values are uniform. Yusniyanti & Kurniati (2017) mentioned that a greater coefficient of variation value indicates uneven data (heterogeneous). On the other hand, the smaller the coefficient of variation value, the more evenly distributed the data is uniform (homogeneous). This low coefficient of variation also indicates that the moisture content has been controlled. The difference in the value of moisture content between replicates of test samples can affect the process and value of other tests, such as the regular density test, the gluing process on wood joints, and the value of testing the static bending strength of *Shorea* sp. in this study can be ignored. Somadona *et al.* (2020) stated that one of the factors that can affect the process and quality of gluing is wood moisture content. Ruhendi *et al.* (2007) added that the bonding of adhesive liquid to wood can be inhibited due to moisture content. The gluing quality will be disrupted due to high moisture content, so the gluing bond becomes weak (Utomo & Dayadi 2023).

The regular density of *Shorea* sp. was 0.56 g/cm$^{3.}$ In comparison, its oven-dried density was 0.54 g/cm^3, which means that the *Shorea* sp. used in this study was included in the light wood group (<0.6) (PIKA 2003), and belongs to strength class III (0.4-0.6 g/cm^3) in the classification of wood strength (Ministry of Environment and Forestry 2020).

Static Bending Strength (MoE and MoR)

Static bending strength tests (MoE and MoR) were carried out on *Shorea* sp. solid wood without a finger jointing process as a control and on finger-jointed using PVAc adhesive with different compression pressure treatments. Statistical analysis using ANOVA was only carried out on wood with finger joints that had been glued (compression pressure). At the same time, the control treatment was not included in the ANOVA because it did not experience the gluing and gluing process, so the test value of the control treatment was only for comparison. The average test values for MoE and MoR can be seen in Table 2.

Table 2. The MoE and MoR of red meranti (*Shorea* sp.) based on differences in forging pressure in finger-jointed and unjointed samples (control)

Treatment	MoE (N/mm)^2	Coefficient of Variation (%)	MoR (N/mm)^2	Coefficient of Variation (%)
P1 (2 bar)	9,080.66	14.65	60.43	11.83
P2 (2.5 bar)	9,367.67	14.87	60.80	11.85
P3 (3 bar)	9,975.53	15.40	61.26	13.29
Control (no joint)	10,017.07	20.33	82.07	13.06

Table 2 shows a difference in MoE and MoR between the treatment of different pressures on the wood joints (P1, P2, P3) and the control treatment without joints (no gluing and forging process). The coefficient of variation of MoE and MoR in this study is also relatively low, indicating the uniformity of data in each treatment, which shows that the procedure for making and testing test samples of wooden finger joints is quite good, controlled, and uniform.

The highest MoE and MoR were obtained in treatment P3 (3 bar compression pressure), which was around 9,975.53 N/mm^2 and 61.26 N/mm^2, respectively. In contrast, the lowest in treatment P1 (2 bar) was around 9,080.66 N/mm^2 and 60.43 N/mm^2. To determine the effect of different treatments of compression pressure on the value of static bending strength (MoE and MoR) in finger-jointed *Shorea* sp., the ANOVA results are presented in Table 3 and Table 4.

Table 3. ANOVA of MoE of finger-jointed *Shorea* sp. at a different compression pressure

Source of Variation	Sum of Squares	Free Degree	Mean Square	F Count	F Table	
					0,05	0,01
Treatment	8,351,060.09	2	4,175,530.04	1.86ns	3.16	5.00
Error	127,757,569.06	57	2,241,360.86	-	-	-
Total	136,108,629.14	59	-	-	-	-

Note: ns = insignificant effect.

Table 4. ANOVA of MoR of finger-jointed *Shorea* sp. at a different compression pressure

Source of Variation	Sum of Squares	Free Degree	Mean Square	F Count	F Table	
					0,05	0,01
Treatment	6.97	2	3.49	0.08ns	3.16	5.00
Error	2,516.95	57	44.16	-	-	-
Total	2,523.92	59	-	-	-	-

Note: ns = insignificant effect.

The MoE shows the ability of wood to withstand loads in the elastic region (wood has not yet been damaged), while the MoR shows the strength of wood in withstanding loads until the wood is permanently damaged (plastic region). The modulus of elasticity expresses stiffness as the ability of the material to resist changes in shape or curvature. In contrast, the MoR expresses the strength of the material to withstand the maximum load (maximum strength), namely when the material fails.

ANOVA of MoE in Table 3 shows that different compression pressures (2 bar, 2.5 bar, and 3 bar) in making finger joints in *Shorea* sp. have no significant effect on the MoE. Similar results in Table 4, ANOVA of MoR also show that the treatment of different compression pressures (2 bar, 2.5 bar, and 3 bar) in making finger joints in *Shorea* sp. has no significant effect on the MoR value. In Figure 4 and Figure 5, it is clear that there is a tendency in the treatment to have the more substantial the compression pressure, the higher the MoE and MoR, although these values are still lower than *Shorea* sp. without finger joints (control). The quality of the finger joint gluing using PVAc adhesive with 2 bar, 2.5 bar, and 3 bar compression pressure showed that almost all damage occurred in the finger joint area, as shown in Figure 6. Wulandari *et al.* (2023) stated that one of the factors affecting the quality of wood gluing is the pressure of the felts.

Figure 6. Damage to the *Shorea* sp. finger joints in the static bending strength test

In this study, the MoE and MoR values were higher the higher the compression pressure treatment, indicating that there was a better gluing process as the compression pressure increased. Wood stiffness and strength properties by gluing wood joints will be better if the appropriate pressure is applied. This is because there is better penetration of PVAc adhesive at a compression pressure of 3 bar (P3), forming a better adhesive line than the adhesive line at a compression pressure of 2 bar (P1) and 2.5 bar (P2). The effect of compression pressure on adhesive penetration is also influenced by the porosity of the wood, where the end face of the wood joint (axial plane) is the most porous compared to the radial and tangential planes. Penetration of the adhesive into the fibers and vessels is easy when given sufficient compression pressure. If the compression pressure is too low, then the penetration will be too small to form a thick adhesive line, but vice versa, if the compression pressure is too enormous, then the penetration can be too deep, creating an adhesive line that is too thin (starving joint). Ruhendi *et al.* (2007) stated that adhesive penetration is influenced by the pressure of the felts and the porosity of the wood, so it is difficult to get a good and robust adhesive line to withstand the load on the axial plane (wood joints).

Manual application of PVAc adhesive using a brush is also thought to cause inconsistent weight, uneven distribution of adhesive, and non-uniform thickness, so when given a different amount of compression pressure, the distribution of adhesive to the surface of the wood is also different, causing uneven distribution and the formation of poor adhesive lines resulting in low adhesive firmness so that the MoE and MoR values decrease. Ruhendi *et al.* (2007) mentioned that adhesive coating distributes the adhesive to form a uniform thickness on the adhesive plane and controls the adhesive amount on the wood surface. It is recommended that the adhesive application on the finger joint end of the wooden board be carried out using a roller glue spreader or other type of tool at the end of the wooden joint so that the adhesive distribution is more controlled, consistent, and evenly distributed. The optimum distribution of suitable adhesive at the boundary area between the adhesive and the bonded material is an essential factor that can provide good bonding conditions. (Radiitya & Massijaya 2005).

The MoE and MoR values of the *Shorea* sp. finger joint treatment using exterior type PVAc adhesive at all compression pressures (P1, P2, P3) in this study were lower than the control treatment (without joints). The MoE value in the P3 (3 bar) treatment of 9,975.53 N/mm^2 almost reached the MoE value of the control treatment of 10,017.07 N/mm^2, while the MoR values of all finger joint treatments tended to be uniform and relatively low compared to the control treatment. According to Sinaga (1994), the presence of joints in wood is the weakest point of wood as a construction material. The joint causes a weakening of the strength of the wood where the joint of bolts, nails, and pegs reduces the strength to 30%, 50%, and 60% of its original strength, while the use of adhesives in the joint can reach 100% strength if the joint is well designed and carried out.

The MoR of the control *Shorea* sp. without joints was 82.07 N/mm^2 (836.88 kg/cm^2), including strength class II (725-1,100 kg/cm^2), while all the joinery treatments with exterior type PVAc adhesive ranged from 60.43 N/mm^2 (616.22 kg/cm^2)

to 61.26 N/mm^2 (624.68 kg/cm^2) including in strength class III (500-725 kg/cm^2) in the classification of wood strength (Ministry of Environment and Forestry, 2020). The use of a compression pressure of more than 3 bar in meranti merah timber finger joints with PVAc adhesive is necessary to obtain MoE and MoR values that reach the strength class of the control meranti merah or a higher strength class, in connection with the results of the study which showed a tendency that the higher the compression pressure, the higher the MoE and MoR values.

D. CONCLUSION

1. The regular and oven-dried density of *Shorea* sp. of 0.56 g/cm^3 and 0.54 g/cm^3 under normal moisture content conditions of 11.01% means it is included in the light wood group (<0.6 g/ cm^3).
2. ANOVA showed a non-significant effect of compression pressure treatment (2 bar, 2.5 bar, 3 bar) on the MoE and MoR values of *Shorea* sp. finger joints with exterior type PVAc adhesive.
3. The MoE value of the control *Shorea* sp. treatment (without joint) of 10,017.17 N/mm^2 was higher than all the wood-joining treatments with exterior type PVAc adhesive ranging from 9,080.66 N/mm^2 to 9,975.53 N/mm^2, as well as the MoR value of the control of 82.07 N/mm^2 higher than all the wood-joining treatments with exterior type PVAc adhesive ranging from 60.43 N/mm^2 to 61.26 N/mm^2.
4. The greater the compression pressure in the process of gluing *Shorea* sp. joints with exterior type PVAc adhesive, the highest MoE and MoR values in the P3 treatment (3 bar compression pressure) were 9,975.53 N/mm^2 and 61.26 N/mm^2, respectively.

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