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The Utilization Rubber Wood Finger Joint Laminated for Furniture Application

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ABSTRACT

Rubber wood (*Hevea brasiliensis*) was considered a promising alternative material in furniture manufacturing due to its favorable physical and mechanical properties, sufficient availability, and relatively high economic value. However, it lacked natural durability and was vulnerable to insect and fungal attacks, requiring preservative treatment before use. This study aimed to evaluate the performance of Finger Joint Laminated (FJL) products made from preservative-treated rubber wood as a potential raw material for furniture. The research involved wood selection, preservative treatment using deltamethrin and boric acid via the vacuum-pressure method, fabrication of FJL using three adhesive compositions (PVAc, PVAc + 5% hardener, and PVAc + 15% hardener), and testing of physical (moisture content and density) and mechanical (modulus of elasticity and modulus of rupture) properties according to BS 373:1957 standards. The results showed that all FJL variants met the density requirements stated in SNI 01-0608-2017. The FJL bonded with 15% PVAc and hardener achieved the highest density and exhibited superior mechanical strength. Although the addition of hardener increased the moisture content, it remained within the acceptable limit (<15%) as defined in SNI 01-0608-1989. The improvement in mechanical performance was attributed to enhanced cross-linking in the adhesive. Some mechanical failures were likely caused by uneven adhesive application. In conclusion, rubber wood treated with preservatives and processed into FJL with optimal adhesive composition demonstrated strong potential as material for furniture production.

Keyword: Delthamethrin, Finger Joint Laminated, Polyvinyl Acetate, Rubber Wood

1. Introduction

Rubber wood (*Hevea brasiliensis*) has become an important alternative material in the wood industry due to its growing availability and potential as a sustainable substitute for wood from natural forests. Rubber wood was considered to have good basic physical properties, relatively high economic value, and was abundantly available in plantation forests [1]-[3]. It was generally obtained from 25–30-year-old rubber trees that had passed their productive latex-producing phase and required replanting [4]. The use of plantation-sourced wood, including rubber wood, had increased significantly as it was used in furniture, parquet, flooring, and building components. Additionally, increasing global demand for low-cost and environmentally friendly furniture further supported the use of rubber wood [5].

Rubber wood can be used for various purposes. This type has the potential to be used in making furniture but requires further utilization efforts [6]. However, despite its advantages, rubber wood had low natural durability and was highly susceptible to insect and fungal attacks, especially by termites and blue stain fungi [7]. Rubberwood requires preservative treatment using chemicals before use [8]. Chemical preservation, such as treatment with deltamethrin and boric acid, was necessary to extend the service life of the wood, reduce biological degradation, and enhance its performance in end-use applications [8]. Among the effective preservation methods, treatments using a combination of deltamethrin and boric acid have been shown to significantly improve resistance against termites and decay fungi [9]. Without treatment, rubber wood would deteriorate rapidly, especially in tropical climates with high humidity.

To optimize the use of rubber wood for structural and aesthetic applications, several value-added processing techniques had been explored. One of the most promising approaches was the manufacture of engineered wood products (EWP), including finger joint laminated (FJL) boards. FJL allowed the utilization of short wood pieces by joining and laminating them into longer, stable, and dimensionally consistent products, reducing waste and improving strength and appearance [10]. Moreover, FJL provided a reliable solution for producing high-quality furniture components from plantation wood species, especially when combined with proper preservation methods and adhesive technology [11,12]. The success of FJL manufacturing largely depends on the quality of the adhesive used, as it directly influences the mechanical performance and durability of the joints. In this study, polyvinyl acetate (PVAc) was selected as the adhesive due to its strong bonding capability, ease of application, low cost, and non-toxic nature, making it suitable for indoor furniture applications. PVAc is also compatible with rubberwood, which has moderate density and porosity, allowing good adhesive penetration and film formation. According to [13], PVAc adhesives are widely used in wood products due to their clean handling, fast setting times, and sufficient water resistance for non-structural uses. Additionally, its performance can be enhanced with the addition of hardeners, which accelerate curing and improve bonding strength. Therefore, PVAc with hardener offers a practical and effective adhesive option for improving the performance of FJL rubberwood intended for furniture use.

The wood preservation carried out by each company is different, depending on its market share. CV Citra Jepara has preserved rubber wood using deltamethrin using various methods (brushing, soaking and vacuum-pressing). The rubber wood is then used as raw material for making finger joint laminate (FJL) for furniture products. Information regarding the use of deltamethrin-treated rubber wood for FJL, particularly in furniture applications, remained limited. Based on the above considerations, it was necessary to conduct further research on the use of rubber wood as raw material for furniture through the production of FJL. Based on the description above, this research aims to evaluate the physical and mechanical properties specifically the moisture content (MC), modulus of elasticity (MOE), and modulus of rupture (MOR) of FJL made from deltamethrin-preserved rubberwood using PVAc adhesive with and without hardener. The results are expected to provide insight into the feasibility of using preserved rubberwood in engineered wood products for the furniture industry.

2. Method

2.1 Materials and Tools

The materials used in this research included rubberwood with a diameter of 20 cm and a length of 2 m, sourced from CV. Citra Jepara, preservatives in the form of deltamethrin and boric acid at a concentration of 3% and polyvinyl acetate (PVAc) adhesive combined with a hardener (Yona Bond). The equipment employed comprised a Universal Testing Machine (UTM) Instron, a moisture meter (Lutron MS-7003), calipers (Mitutoyo), a vacuum-pressure preservative treatment apparatus, a finger jointing machine, and brushes for adhesive application.

2.2 Wood Preparation

Rubberwood was selected by taking into account its defect-free condition (free from visual defects such as knots, cracks, warping and discoloration). The wood was then cut into dimensions of 20 cm (length) x 5 cm (width) x 2 cm (thickness). The moisture content of the rubberwood used was approximately 12%.

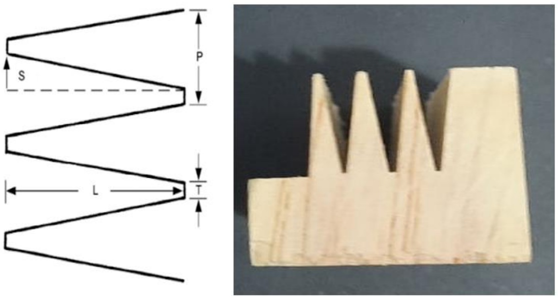
2.3 Preservation Process

The preservation applied to the samples was carried out using the vacuum-press method. The prepared test samples were painted at both ends to ensure that the preservative did not enter through those parts. All test samples were weighed, and their length, width, and thickness were measured. The vacuum-pressure process was conducted using a vacuum tube at CV. Citra Jepara. The prepared preservation test samples were then placed into a preservation tube and sealed. The next step involved applying a vacuum with a pressure of up to 30 cm Hg for 30 minutes. After the vacuum process was completed, the preservative was filled into the tube until it was full. Pressure was then applied until it reached 10–12 kg/cm^2 and was maintained by alternating the pressure between 10–12 kg/cm² approximately four times, each for five minutes. The final stage involved removing the preservative and taking the wood out of the tube. The preserved test samples were then drained and reweighed.

2.4 Manufacturing of Finger Joints Laminated

The preserved test samples were then formed into finger joint components. The finger joints were made using a machine (Figure 1) with specifications as shown in Figure 2.

Figure 1. Finger joint machine



Note:
p = 0.4 mm,
t = 0.1 mm,
l = 13 mm,
s = slope

Figure 2. Finger joint connection specifications

Samples that had been formed into finger joint pieces were then applied with adhesive using three different compositions: PVAc, PVAc + 5% Hardener, and PVAc + 15% Hardener. The two finger joint components with adhesive applied were then placed in a finger joint press machine and pressed for approximately 3 minutes.

2.5 Testing

Testing of the physical properties of wood in this research included moisture content and wood density. The test procedure followed BS 373-1957 and was carried out gravimetrically. The mechanical testing conducted in this research was static bending testing, also referring to the BS 373-1957 standard. Testing of the Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) was performed using a Universal Testing Machine (UTM) with a centralized one-point loading method. In this setup, the test sample was supported at both ends and loaded at the center, allowing for the assessment of its flexural strength and deformation behavior under a concentrated load. The test sample was placed horizontally with a span of 28 cm, and the loading speed was set at 10 mm/minute. To calculate the MOE and MOR, the following formulas were used:

$$MOE = \frac{\Delta P\, L^3}{4\, \Delta y\, b\, h^3} \qquad MOR = \frac{3\, PL}{2\, b\, h^2} \tag{1}$$

Where: MOE: Modulus of elasticity (MPa); ΔP: Change in load below the proportional limit (kg); L: Span length (cm); Δy: Change in deflection due to load (cm); b: Width of test specimen (cm); h: Thickness of test specimen (cm); MOR: Modulus of rupture (MPa); P: Maximum load (kg)

2.6 Data Analysis

The experimental design for testing the physical and mechanical properties of FJL used a completely randomized design (CRD) with one factor, namely the adhesive component consisting of three levels: PVAc, PVAc + 5% hardener, and PVAc + 15% hardener. The experiment was conducted with three replications. The data obtained were analyzed using analysis of variance (ANOVA). If the results of the variance analysis showed significant differences, the analysis was continued with the Duncan test to determine the factors that had a significant effect [14]. The analysis was performed using the IBM SPSS 27 software.

3. Results and discussions

3.1 Density

Wood density is an important physical property because it is related to other properties. Wood density is the ratio between mass and volume expressed in kg/m3 or g/cm3. Apart from that, wood density also states the amount of material that makes up the cell walls or other substances that provide strength to the wood [15]. Density is related to strength, wood quality, dimensional changes, and workmanship or processing, as well as the quality of the final product produced [16,17]. ANOVA results showed that the addition of a hardener has a significant effect on the density value ($p<0.05$).

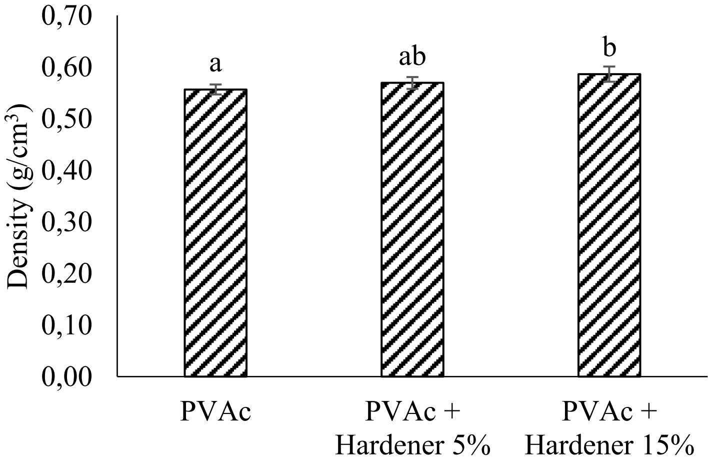


Figure 3. FJL density values of rubber wood in various treatments

The research results showed that FJL made from rubber wood with PVAc adhesive without hardener and with the addition of hardener with different percentages had different density values (Figure 3). The density value of FJL with PVAc adhesive without the addition of hardener is 0.56 g/cm3, while FJL made with PVAc adhesive with the addition of 5% and 15% hardener has a density of 0.57 g/cm3 and 0.59 g/cm3. According to [18], solid rubberwood has density range 0.54-0.65 g/cm3. High-density values correspond to higher wood strength. However, in the case of FJL, the presence of adhesive also contributes to the overall density, particularly when hardeners or higher solid-content formulations are used. Wood density is correlated with wood mechanical properties (MOE, MOR, and CS) [17]. This is also in accordance with [19], that density is one of the things that greatly influences the mechanical properties of wood apart from the deformation of cell shape, arrangement of vessels, and position of growth in the stem. Higher density particularly at 15% hardener correlates with improved mechanical strength, making the FJL more suitable for furniture applications requiring higher structural performance.

The resulting FJL density value meets SNI 0608-2017 which requires wood materials for furniture to have a density above 0.4 [20]. FJL with the highest density (PVAc + hardener 15%) has the potential to have better strength than other treatments. Thus, FJL originated from deltamethrin-cured rubber wood with PVAc adhesive can be a material for making furniture.

3.2 Moisture Content

Moisture Content (MC) is an important factor in determining wood quality. The research results showed that the MC of FJL with PVAc adhesive without the addition of hardener was 10.53%, while FJL with the addition of 5% and 15% hardener had an MC of 10.78% and 10.81% respectively (Figure 4). The slight increase in moisture content (MC) observed with the addition of 5% and 15% hardener (from 10.53% to

10.81%) may be attributed to the chemical composition of the hardener, which can increase the hygroscopicity of the adhesive system. Hardeners, especially those containing polyisocyanates or other reactive agents, may absorb and retain more moisture during the curing process due to their polar nature and chemical interactions with ambient humidity [13]. Furthermore, the cross-linking reaction promoted by the hardener can result in a denser adhesive matrix that retains more bound water, leading to a slightly higher MC in the finished FJL product [21]. The results of ANOVA ($p<0.05$) showed that the addition of hardener has a significant effect on the water content value.

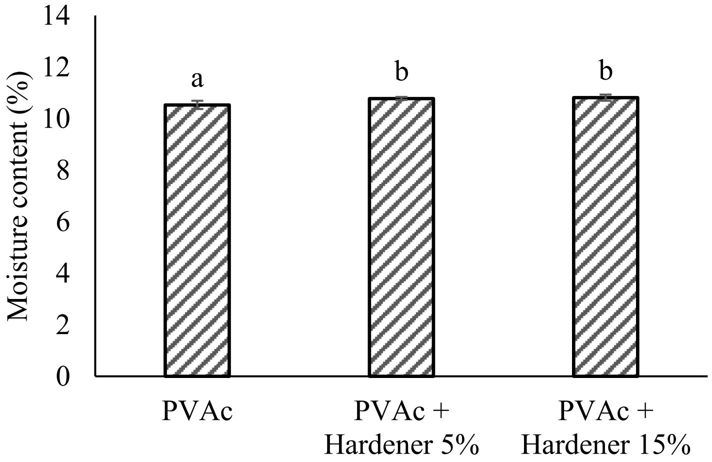


Figure 4. FJL moisture content value of rubber wood in various treatments

The MC value of composite boards is influenced by various factors such as material density, type and amount of adhesive, and relative air humidity [22]. A high MC value will tend to reduce the strength of the wood because water in the wood cavity will weaken the bonds between the fibers. In general, wood strength increases as MC decreases or MC is inversely proportional to wood strength [23,24]. Moisture content also influences dimensional stability [25], and wood durability againts wood-destroying organisms such as termites and fungi. In addition, MC also influences adhesion and joints [26]. The use of wood or artificial boards as raw materials for furniture usually requires a lamination process, so low MC is very important to produce quality products.

Overall, the addition of hardener to the adhesive for making FJL causes an increase in the MC value but is still within the acceptable range. The moisture content of wood that can be used for the furniture industry according to SNI 01-0608-89 is <15% [27]. Thus, making FJL with PVAc adhesive with the addition of hardener in this research can be utilized as raw material for furniture. Compared to previous research on preservative treatment and bonding performance of rubberwood using PVAc adhesive, the current study demonstrates notable improvements with the incorporation of a hardener. Earlier studies, such as those by [28,29], generally utilized PVAc adhesive without any curing agents, resulting in longer pressing times and less consistent bonding performance, particularly when the wood was treated with preservatives. In contrast, the addition of a hardener in this study improved the adhesive’s curing rate and compatibility with treated rubberwood surfaces, leading to stronger and more reliable finger joints.

3.3 Modulus of Elasticity and Modulus of Rupture

Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) are key indicators of a material’s mechanical performance, reflecting its stiffness and bending strength, respectively. Based on the results of ANOVA, it showed that the addition of hardener has a significant effect on the MOE value ($p<0.05$) (Figure 5). The results of statistical analysis show that the addition of a hardener has a significant effect on the MOR value (Figure 6). In the FJL test, the MOE and MOR values increased along with the addition of hardener. This is in line with research by [30] which states that the addition of a hardener can improve the mechanical properties of composite boards. According to [31], during the bonding process, several complex chemical and physical changes occur when the adhesive material changes from a viscous liquid to a hard solid. The strength value or mechanical properties of a board or composite product can increase along with the degree of cross-linking and molecular weight [32]. The presence of hardener can increase cross-linking thereby improving the mechanical properties of FJL. In SNI 0608 2017 concerning wood for furniture, MOE and MOR values are not mentioned, only the requirements for wood strength classes are explained with the difference between load-bearing and non-load-bearing. In this study, the mechanical properties of the rubberwood FJL produced are included in strength classes IV-V referring to the SNI 7973:2013 standard [33]. Based on this, the rubber FJL produced in this study can be used as furniture that does not bear loads.

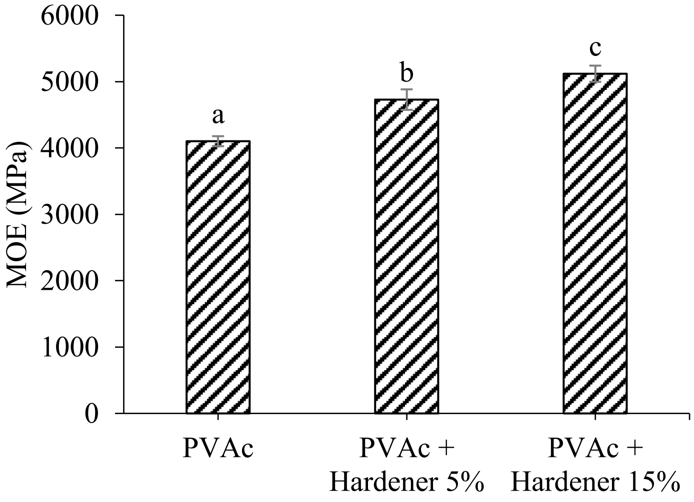


Figure 5. MOE FJL value of rubber wood in various treatments

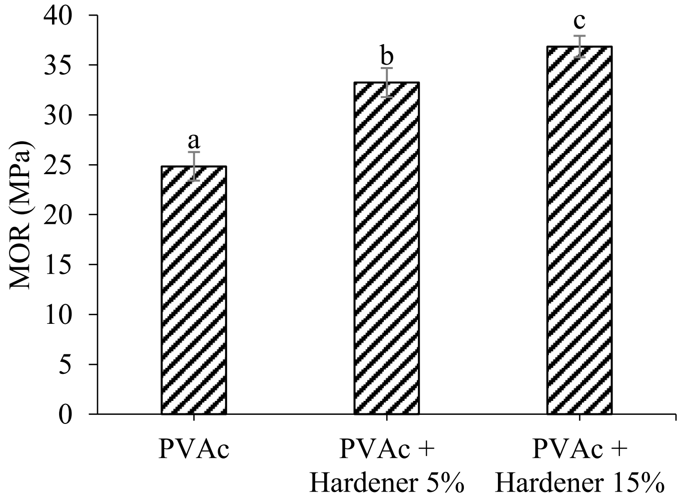


Figure 6. MOR FJL value of rubber wood in various treatments

The damage that occurred in the MOE and MOR tests (Figure 7) was on the FJL side connection. This is thought to be due to poor and uneven adhesive coating. The uneven adhesive coating can be caused by an uneven surface of the material or an inappropriate adhesive coating method. There is very little damage to the wood and what is visible is the cracks in the wood. This is thought to be because the working load has not been able to damage the wood completely and only partially [34]. When compared to previous studies on FJL rubberwood for furniture applications, such as those conducted by [28,35], a similar trend in failure at the joint line was also reported especially in samples without proper surface preparation or without hardener additives in the adhesive. However, those studies emphasized that with optimal finger geometry, proper surface planning, and uniform adhesive distribution, the joint strength can reach or even surpass the strength of the clear wood.

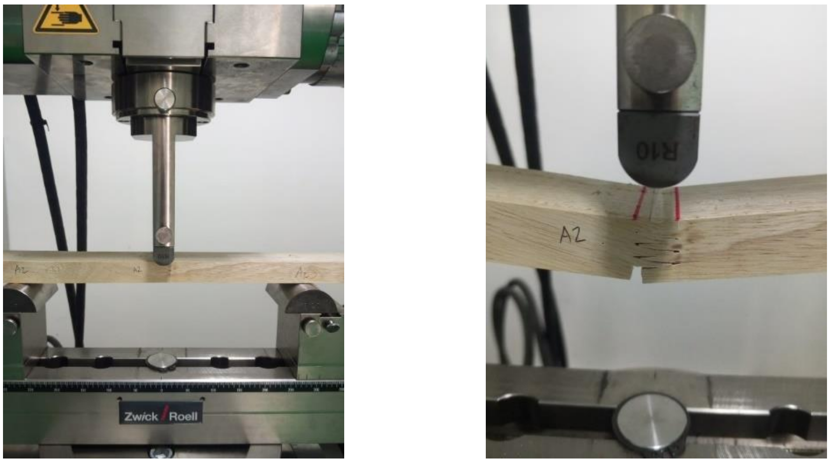


Figure 7. FJL damage during mechanical testing

4. Conclusion

The resulting FJL density value meets SNI 0608-2017. FJL with the highest density, namely FJL with 15% PVAc + hardener adhesive, has the potential to have better strength than other treatments. The addition of a hardener to the adhesive for making FJL causes an increase in the MC value, but it is still within the accepted range, namely <15% according to SNI 01-0608-89. The presence of a hardener can increase the cross-linking that occurs so that it can improve the mechanical properties of FJL as the amount increases. The addition of a hardener increases adhesive cross-linking, which leads to improved internal bonding strength and stiffness, thereby enhancing both MOE and MOR values of the FJL product. The damage that occurred in the MOE and MOR tests was thought to be due to poor and uneven adhesive coating. Therefore, improving adhesive coating techniques and ensuring surface flatness and cleanliness during the jointing process is crucial for enhancing the structural reliability of rubberwood FJL in furniture manufacturing. Suggestions for further research are to carry out durability testing, SEM, and FTIR to support existing data.

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