Performance of glued laminated timber (glulam) made from Rubberwood with different lamina assembly patterns and adhesive spreads rates

Performance of glued laminated timber (glulam) made from Rubberwood with different lamina assembly patterns and adhesive spreads rates

A Hermawan[1]*, A Z Mohammad Sofi[2] and M N Roszalli[3]

[1] Department of Bio and Natural Resource Technology, Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, 17600 Jeli, Kelantan, Malaysia
2 Department of Basic Science, Technology and Engineering, Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, 17600 Jeli, Kelantan, Malaysia
[3] Forest Resources Technology Program, Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, 17600 Jeli, Kelantan, Malaysia

* Corresponding author: andi@umk.edu.my

Abstract. Glued laminated timber (glulam) is a great building material with strong mechanical properties that comprises laminated layers of wood (lamina) glued together with long-lasting structural adhesives. As the supply of large dimensional lumber for construction projects has been in shortage, glulam is the ideal material to replace the lumber because it can be made in various sizes and shapes, including unique arches using relatively small dimensional lumber. This research aims to investigate the effects of different lamina assembly patterns and adhesive spread rates on the physical and mechanical properties of rubberwood glulam. For this purpose, the lab scale of the 3-ply glulam was made from homogenous grades lamina of low-MOE, average-MOE, and high-MOE. In addition, the lab scale of the 3-ply glulam was also produced from mixed grades lamina of low-high-low-MOE and high-low-high-MOE. The glulam was tested to evaluate the physical and mechanical properties based on the Japanese Industrial Standards for glulam (JAS 234-2003). The results show that the lamina assembly patterns significantly affect the mechanical properties of the glulam. Accordingly, the glulam made from a high-MOE lamina at its compression and tension surfaces has the best mechanical properties compared to that made from the other assembly patterns. In addition, although the difference was insignificant, the results showed that adhesive spread rate has positively affected the mechanical properties of the glulam. The results showed that Rubberwood has the potential to be used as raw material for glulam production.

Keywords: Glulam; Rubberwood; physical and mechanical properties; assembly pattern.

1. Introduction

Glulam is a well-known wood-based product that has many benefits over solid wood. Although glulam manufacturing is more expensive than traditional solid wood, it is generally cheaper compared to other materials, such as steel. In addition, structural glulam is designed to free from defect knots, resulting in a higher strength due to removing sloping grains all around the laminas [1,2]. Therefore, glulam is much higher in the strength-to-weight ratio, which makes glulam beams an excellent choice to cover longer spans [3].

On the other hand, it is well known that lamina assembly patterns could affect the mechanical properties of glulam. Studies on the effect of lamina assembly patterns on the bending and creep behavior of glulam have been conducted by some researchers. The results revealed that lamina assembly patterns could affect glulam bending efficiency, but they have a more negligible impact on creep properties [4,5]. These findings suggested that glulam could be produced using different grades of laminas to reduce production costs while maintaining its mechanical properties. In addition, the mechanical properties of glulam are affected by the adhesive spread rate. Generally, increasing the amount of adhesive could improve the mechanical properties of glulam [6]. However, the excessive adhesive spread rate on the less permeable lamina could decrease the mechanical properties of glulam because a thicker glue line is not favorable [7]. Therefore, avoiding excessive adhesive while maintaining a reasonable manufacturing cost and quality is feasible by adjusting the adhesive spread rate [8].

This study investigates the potential of Rubberwood used as raw material for glulam production. For this purpose, the physical and mechanical properties of glulam made from Rubberwood were investigated. The focus of the study was on the effects of different lamina assembly patterns and adhesive spread rates on the physical and mechanical properties of the glulam.

2. Materials and Methods

2.1. Materials

Rubberwood obtained from a local sawmill in Jeli, Kelantan, was used in this study. In glulam production, a PVAc-based wood adhesive is used as a binder. Rubberwood was dried and cut to produce 60 laminas with dimensions of 500 mm length, 50 mm width, and 6 mm thick. The average moisture content of the lamina was 10.6%, with an average density of 0.56 g/cm^3.

2.2. Methods

2.2.1. Lamina grading. A universal testing machine (UTM) was used to evaluate the modulus of elasticity (MOE) of the lamina. Based on its MOE and standard deviation (SD), the lamina was categorized into high-MOE (MOE_h), average-MOE (MOE_{ave}), and low-MOE (MOE_l). The high-MOE lamina has $MOE_h > MOE + SD$. The average-MOE lamina has $MOE - SD \ll MOE_{ave} \ll MOE + SD$. While the low-MOE lamina has $MOE_l < MOE - SD$.

2.2.2. Glulam production. Lab-scale 3-ply glulam was produced with five assembly patterns, as shown in Figure 1. In addition, to evaluate the effect of adhesive spread rate on the physical and mechanical properties of the glulam, a double-sided spread rate of 100 and 200 g/m^2 was applied to produce glulam using homogenous average-MOE lamina. The glulam was pressed with a manual clamping system at room temperature for 24 hours.

2.2.3. Glulam properties evaluation. The physical and mechanical properties of glulam produced in this study were evaluated based on the Japanese Agricultural Standard for glued laminated timber (JAS 234-2003). The testing includes moisture content, density, and bending properties involving three replications for each test.

3. Results and Discussion

3.1. Lamina grading

The typical load of each lamina plotted to its deflection is presented in Figure 2. The figure showed that the high-MOE lamina typically has a higher load at any deflection point and vice versa for the low-MOE lamina. It is well known that wood properties, such as strength, depend on its position in the radial and longitudinal direction of the tree. Therefore, the MOE of the wood from the single stem could vary wildly, depending on its position. For instance, the wood near the pith generally has lower MOE due to a higher percentage of juvenile wood than that near the bark. The same tendency was found at the base than at the top of the tree. In addition, the properties of wood are also affected by the wood defect, such as knot and sloping grain orientation. From these results above, the lamina classified into high- and low-MOE when its MOE was above 5871 and below 2103 MPa, respectively.

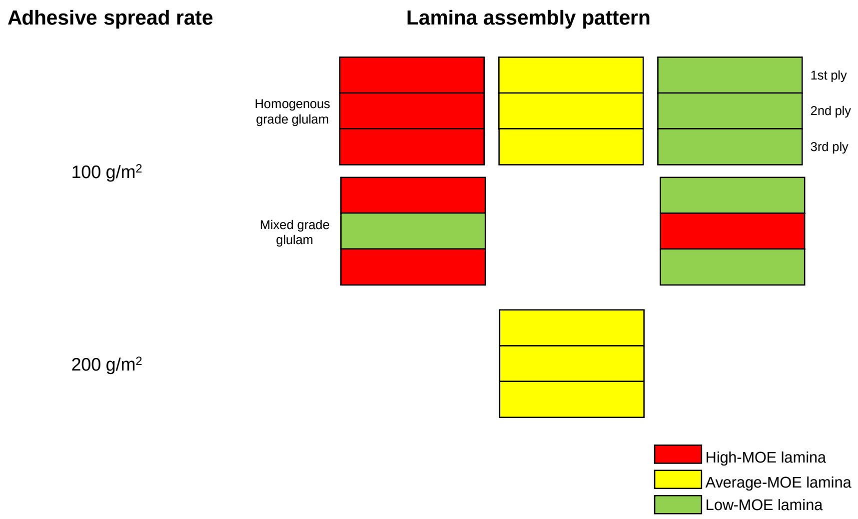

Figure 1. Systematic diagram of lamina assembly patterns for glulam production.

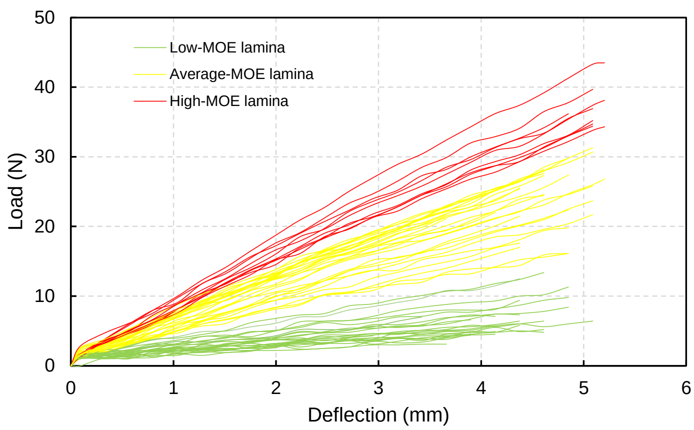

Figure 2. The load and deflection of each lamina.

Figure 3 shows the number of laminas based on the classification used in this study. The average-MOE lamina was 23 laminas, while the high-MOE and low-MOE laminas were 15 and 22, respectively. However, based on the Japanese Agricultural Standard (JAS) for homogenous grade glulam, the required MOE for the lamina is above 4500 MPa. Therefore, only the high- and some average-MOE laminas have fulfilled the requirement. These results suggest that care has to be taken when using Rubberwood as raw material for glulam manufacturing.

3.2. The physical properties of the glulam

3.2.1. Effect of adhesive spread rate on density and moisture content. Figure 4 presents the average density and moisture content of glulam made from homogenous average-MOE lamina with different adhesive spread rates of 100 and 200 g/m^2. The average density was 0.65 and 0.67 g/cm^3 for the glulam made with the adhesive spread rate of 100 and 200 g/m^2, respectively. In addition, the average moister content of the glulam with the adhesive spread rate of 100 and 200 g/m^2 was 14.7 and 15.2%, respectively. The results showed that the higher the adhesive spread rate, the higher the density and moisture content of the glulam. This is because the amount of the adhesive applied to the glulam slightly affects the total mass increment and water absorbed by the lamina. However, according to the analysis of variance (ANOVA), the effect of the adhesive spread rate on the density and moisture content of glulam was insignificant. In addition, the moisture content required to meet JAS 234-2003 should be less than 15%.

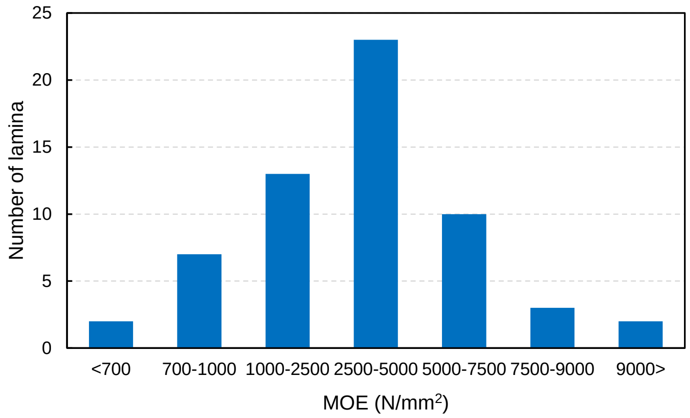

Figure 3. The number of lamina based on its MOE.

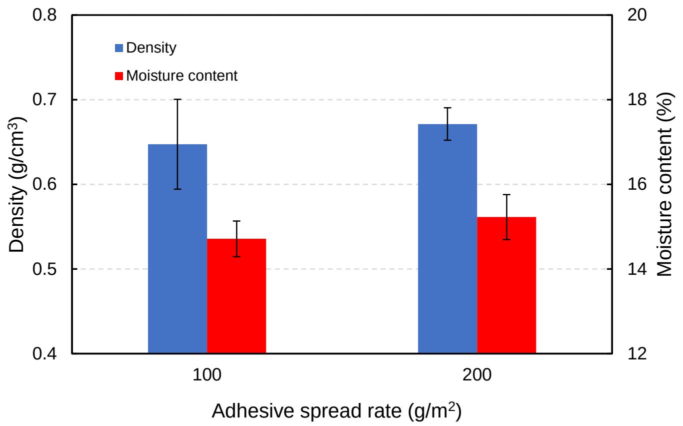

Figure 4. Effect of adhesive spread rate on density and moisture content of glulam.

3.2.2. Effect of lamina assembly pattern on density and moisture content. Figure 5 presents the average density and moisture content of the glulam made from different lamina assembly patterns. The average density was 0.58, 0.67, 0.68, 0.58, and 0.62 g/cm^3 for the glulam made from homogenous low-, average-, high-MOE, mixed low-high-low-, and high-low-high-MOE lamina, respectively. The results showed that the lamina assembly patterns affect the glulam density, the glulam made from a higher MOE has a higher density. However, based on the analysis of variance, the effect of lamina assembly patterns on the density of glulam was insignificant. In this study, the density of all the glulam meets the requirement of JAS 234-2003, which is between 0.56-0.64 g/cm^3. In addition, the average moisture content was 16.4, 15.3, 14.8, 16.0, and 15.5% for the glulam made from homogenous low-, average-, high-MOE, mixed low-high-low-, and high-low-high-MOE lamina, respectively. It was found that the glulam made from homogenous low-MOE lamina has the highest moisture content, while that made from homogenous high-MOE lamina has the lowest moisture content. However, based on the analysis of variance, the difference was not significant. The results showed that most glulams did not meet the standard requirement.

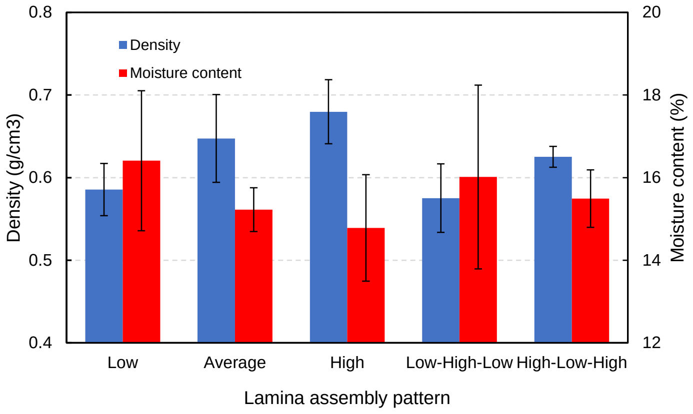

Figure 5. Effect of lamina assembly pattern on density and moisture content of glulam.

3.3. The mechanical properties of the glulam

3.3.1. Effect of adhesive spread rate on bending properties. Figure 6 presents the average MOR and MOE of glulam made from homogenous average-MOE with different adhesive spread rates of 100 and 200 g/m^2. The average MOR and MOE of the glulam made with the adhesive spread rate of 100 and 200 g/m^2 were 36.80 and 3689, and 46.30 and 4411 MPa, respectively. This result shows that the higher the adhesive spread rate, the higher the MOR and MOE of the glulam. This is because a higher adhesive spread rate leads to extensive physical and chemical bonding between the lamina and adhesive, thus improving the bending properties. However, based on the analysis of variance, the effect of the adhesive spread on the bending properties was insignificant. In addition, according to the JAS 234-2003, the MOR and MOE of homogenous grade 3-ply glulam should be higher than 22.5 and 5500 MPa, respectively. The results show that the glulam has fulfilled the required standard for the MOR but not for the MOE.

3.3.2. Effect of lamina assembly patterns on bending properties. Figure 7 presents the average MOR and MOE of the glulam made from different assembly patterns. Based on the figure, the highest average MOR and MOE were 54.69 and 6108 MPa, respectively, obtained from glulam made from the homogenous high-MOE lamina, followed by the glulam made from the mixed high-low-high-MOE lamina. While the lowest average MOR and MOE were 12.60 and 1274 MPa obtained from glulam made from the homogenous low-MOE lamina. The result shows that all the glulam met the standard requirement for the MOR except those made from uniform low-MOE and mixed low-high-low-MOE. In the case of MOE, the result shows that all the glulam did not meet the requirement, except for the glulam made from the homogenous high-MOE and mixed high-low-high-MOE lamina. These results imply that the assembly pattern affects the bending properties of the glulam. It was clear that the glulam made from a high-MOE lamina at its upper and lower surfaces has a higher MOR and MOE than the other assembly patterns. During the bending test, the upper surface of the glulam would exhibit compression, and the bottom surface is in tension, while the neutral axis is the zero-stress region. Thus, using high-MOE lamina on the upper and lower surfaces could resist the load higher than the other categories of the lamina. Therefore, using high-MOE in the middle of mixed low-high-low-MOE glulam did not significantly improve the MOR due to the zero-stress region of the glulam.

4. Conclusion

This study investigates the potential of Rubberwood used as raw material for glulam production. The focus of the study was on the effects of different lamina assembly patterns and adhesive spread rates on the physical and mechanical properties of the glulam. The conclusion could be drawn as follows. The effect of the adhesive spread rate on the physical and mechanical of the glulam was not significant. On the other hand, the lamina assembly patterns significantly affect the mechanical properties of the glulam. The glulam made from uniform high-MOE lamina has the highest mechanical properties, followed by the glulam made from the mixed high-low-high-MOE lamina. These assembly patterns met the mechanical properties of the JAS 234-2003 standard for 3-ply homogeneous grade glulam. Therefore, Rubberwood has the potential to be used as raw material for glulam production.

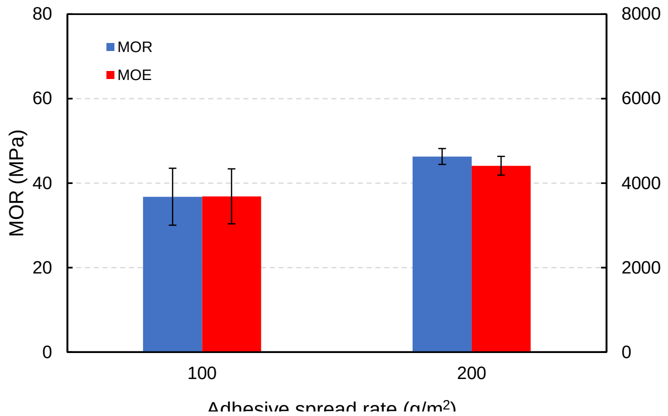

Figure 6. Effect of adhesive spread rate on MOR and MOE of glulam.

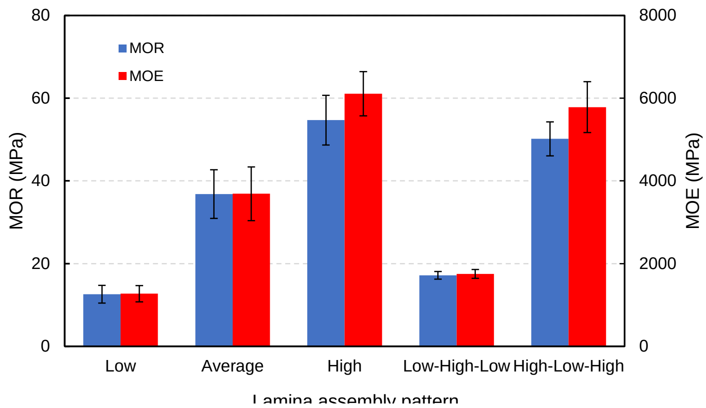

Figure 7. Effect of lamina assembly pattern on MOR and MOE of glulam.

5. References

[1] Lepper MM and Keenan FJ 1986 *Can. J. Civ. Eng.* **13** 445
[2] Milner HR 2018 *Aust. J. Struct. Eng.* **19** 256
[3] Thorhallsson ER, Hinriksson GI and Snæbjörnsson JT 2017 *Compos. B. Eng.* **115** 300
[4] Gao S, Xu M, Guo N, Zhang Y 2019 *Adv. Civ. Eng.* **2019**
[5] Aratake S, Morita H, and Arima T 2011 *J. Wood Sci.* **57** 267
[6] Raftery G, Harte A, Rodd P 2008 *J. I. Wood Sci.* **18** 24
[7] de Oliveira RG, Gonçalves FG, Segundinho PG, Oliveira JT, Paes JB, Chaves IL, Brito AS 2020 *Maderas-Cienc Tecnol* **22** 495
[8] Khoo PS, Chin KL, Lee CL, H'ng PS, and Hafizuddin MS 2021 *Polymers* **13** 3799