ADHESIVE BOND PERFORMANCE OF FOUR MALAYSIAN TIMBER SPECIES IN GLUE LINE DELAMINATION

How Seok Sean
Wood Lamination Laboratory
Forest Research Institute Malaysia (FRIM), Kepong
52109 Selangor D.E.
Email: howss@frim.gov.my

Sik Huei Shing
Wood Drying Laboratory
Forest Research Institute Malaysia (FRIM), Kepong
52109 Selangor D.E.
Email: sik@frim.gov.my

ABSTRACT

The knowledge on bonding performance of tropical timber species for structural applications is limited. The understanding on the glueability of many Malaysian hardwood species is considered incomprehensive. The correlation between the physical properties of hardwood species and its glueability is generally vague and inconclusive. In this paper, four Malaysian hardwood species were selected based on the criterion of wood density and shrinkage values. Bakau, kelempayan, pulai, and merawan were chosen as case studies to examine on their bonding performance via two different test methods in delamination. The correlations between the performance in delamination and the respective density, as well as its shrinkage values are discussed. In addition, the shear strengths of glue lines of the four selected timber species bonded with Phenol Resorcinol Formaldehyde (PRF) were investigated. Results from cyclic delamination test, block shear tests, and the shrinkage values are discussed. The test results showed that pulai and merawan are suitable to be glue laminated using PRF for application under total exposure condition. However, care on preserving the timber durability is required against decay and insect attack. This information will be useful to the industry to be used as indicator in selection of timber species for assorted lamination purposes. The information can also be used as basis for further examination on lamination performance.

Key words: glulam, shear, adhesion, hardwood.

INTRODUCTION

Bonding performance is one of the most important indicators of how well a timber species would behave in glue lamination. Selection of the right species would ultimately be the prime criteria in gluing, cohered with other criterion such as the mechanical performance and durability towards pest resistance are required to be considered in its intended use.

Delamination occurs when bonding between the lamina is inadequate in resisting moisture cycling. The relativity of the length of separations of glue lines between the lamina, as compared to the original length of glue lines prior to exposure to moisture cycling, can be quantified as the percentage of delamination. Delamination may not be the only type of defects present in laminated wood. However, poor lamination below acceptable criteria (according to the respective testing standards) is deemed to be more serious than other timber defects, such as wood check. This is essentially critical when loading application is concern. The delamination performance below par would pose a greater effect on the strength of a member.

Pertinent literatures on glulam made from our local species have showed that assessment on delamination performance on a wider range of commercial species should be conducted. While selected studies (Tan Y.E. & Zaini U., 1996) & Hamami (1990) can be found, many other pertinent studies were focused on the mechanical performances of the glulam beams (Norshariza Mohd. B. et al., 2015) & (Amirah Ali Chew et al., 2016). As to-date, only a handful of glulam studies made from our local species were experimentally explored on the delamination performance. These includes keruing, resak, merpauh (Hazira et al., 2012), bintangor, meranti, and kempas (Hamami, 1990). The above are among the limited number of studies that are related to the topic of research interest. This indicates the needs in filling up the information gap. In essence, information on the bonding performance of our local timber species is essential to the stakeholders in providing the necessary guidance for selection of suitable timber species based on market demand and availability of supply.

There are 33 commercial wood species that have been listed with the respective gluing characteristics in MS 758:2001 Appendix A. The recommended characteristic of these gluing properties is qualitative - classified as satisfactory or good. Having known that the advancement of adhesive technology has improved tremendously over the years, the adhesive performance and the availability of new types of adhesives in the marketplace is not uncommon. As a result, the bonding characteristics of the listed species may no longer be valid. In relation, equal comparison is important in making fair judgement on the gluing performance of these species; hence, a review on the list in a quantitative manner may be more constructive. Furthermore, the supply of forest timber is scarce. The above list may no longer be sufficient to the stakeholders. There might be more potential species for glue lamination that are not presently available on the list. This could possibly open the door for wider source of timber supply from the lesser known timber species and forest plantations as lamination feedstocks.

The objectives of the study are as follow:

1. To assess the integrity of glue lines of 4 selected Malaysian timber species bonded with Phenol Resorcinol Formaldehyde (PRF).
2. To assess the shear strength of glue lines of the four selected species
3. To relate density and shrinkage value to the bond integrity performance.

In this paper, it addresses the bonding performance of four selected Malaysian hardwood, namely bakau, kelempayan, pulai, and merawan. The suitability of these timbers for glue lamination was assessed based on the performance in delamination tests and shear strength on glue lines. Several other physical properties, such as timber density and shrinkage values were correlated with the results from delamination tests. This information would be useful to the stakeholders in determining the suitability of a timber for glue lamination. Furthermore, the results would provide readers an indicator on the strength and weakness of the timber in the aspect of bonding performance.

METHODOLOGY

Preparation of Samples

Timbers from four (4) selected species, namely bakau, kelempayan, pulai, and merawan were conditioned to Equilibrium Moisture Content (EMC) at 12% in a conditioning chamber. All the timbers were prepared and resized into lamellae, subsequently fabricated into glulam samples, and finally cut into dimensions of test pieces according to the respective test requirements. All the glulam samples were laminated using PRF adhesive.

The oven-dried density and basic density of each timber were measured and calculated based on Equation (1) and (2).

Oven-dried density, $\rho_0 = \frac{m_0}{V_0}$ …(Equation 1)

where,
m_0 is the mass of the test piece in absolute dry condition (kg);
V_0 is the volume of test piece in absolute dry condition (cm^3).

Basic density, $\rho_y = \frac{m_0}{V_{max}}$ …(Equation 2)

where,
m_0 is the mass of the test piece in absolute dry condition (kg);
V_{max} is the green volume of test piece (cm^3).

Delamination Test

a) Vacuum Pressure

The vacuum pressure delamination test was conducted according to MS758:2001. Test pieces of 75 mm length were placed in the vessel filled with water. A vacuum force of between 75 and 85 kPa was applied and held for 5 minutes. The vacuum was released and a pressure between 500 and 600 kPa was applied and held for 1 hour. The same process was repeated for the second cycle. Subsequently, all test pieces were removed from the vessel and dried in a conditioning chamber at 60-70°C and relative humidity of less than 15% for 21 hours. The percentages of delamination were computed using Equation 3. In the event where delamination occurs for more than 5% after the second cycle, the above process was repeated for the 3rd cycle for determination of the final delamination.

b) *Boiling Water Soaking*

In this test method, JAS1152:2007 was adopted. Test pieces of 75 mm length were immersed in boiling water for 4 hours and transferred to water at room temperature (10-25 °C) for 1 hour. Later, test pieces were dried in an oven at 70±3°C until the mass reached between 100-110% of the pretest mass (JAS1152:2007). Observation on the delamination length was marked, measured and calculated using Equation 3.

$$Total\ delamination, \% = \frac{l_{tot\ delam}}{l_{tot\ glue\ line}} \times 100\%$$ …(Equation 3)

where

$l_{\text{tot delam}}$ is the total delamination (mm);

$l_{\text{tot glue line}}$ is the total length of glue line (mm).

Shear Test of Glue Lines

Test pieces at nominal dimension 40 mm x 40 mm (Figure 1) were prepared. The test method was based on MS758:2001. Test pieces were placed under shear loading at a constant rate of deformation at 6.16 cm/min to ensure failure occurred not less than 20 seconds. The calculation of shear strength was obtained using Equation 4.

$$Shear\ strength, f_v = \frac{F_u}{A} \quad \text{...(Equation 4)}$$

where

F_u is the maximum shear load (N);

A is the sheared area (mm).

RESULTS & DISCUSSION

The results computed from oven-dry density and basic density are summarized in Table 1. These results are accompanied by the respective shrinkage values archived from various resources. Comparisons of densities for each timber type are depicted in Figure 1.

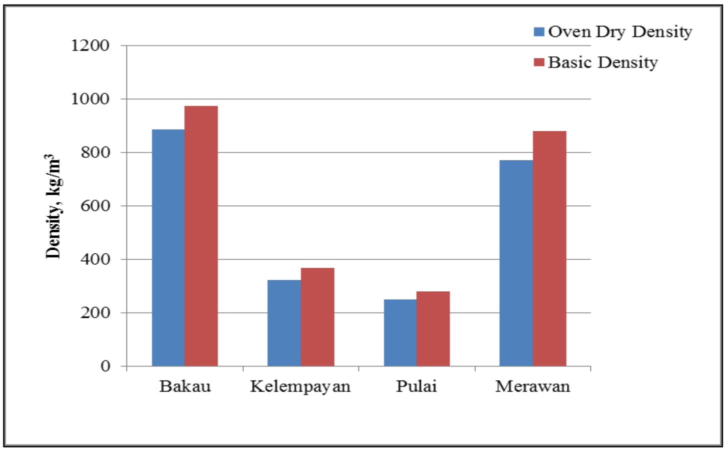
From Table 1, the difference between oven-dry density and basic density is approximately 11%. It appeared that the difference between the two densities increased as the percentage of tangential shrinkage in a timber increased. The correlation between the average radial shrinkage and the difference between the two densities were less significant.

Table 1: Shrinkage value, strength group and the corresponding comparison between oven-dry and basic density of four selected timber

Vernacular Name	Average Shrinkage Value, %			Average Density, kg/m^3		Oven-dry vs. Basic Density, %
	Radial (R)	Tangential (T)	T/R Ratio	Oven Dry Density	Basic Density	
Bakau	1.4[1]	5.1[1]	3.6	974.85	885.88	-9.13
Kelempayan	0.8[2]	2.1[2]	2.5	321.21	366.69	-12.40
Pulai	2.3[1]	2.8[3]	1.2	250.65	280.49	-10.64
Merawan	1.3[4]	3.3[4]	2.5	771.78	880.55	-12.35
	0.9[2]	2.2[2]	2.4			

[1] Lim S.C. (1991)
[2] Lim S.C. et al. (2016)
[3] Sim H.C. (1982)
[4] Anon. (2020)

Figure 1: Comparison between oven-dried density and basic density for the respective four selected timber



Results from vacuum pressure delamination for bakau timber showed higher delamination than from boiling water test. However, the difference between the two results was insignificant. On average, the percentage of delamination from vacuum pressure was higher than boiling water soak test (Table 2). The number of samples that had met the acceptable percentage of total delamination in vacuum pressure test is slightly higher (70%) than boiling water soak test (60%) – Figure 2 and 3.

Overall, the results obtained from the two delamination tests were consistent in agreement with one another. All the selected timbers, except for bakau, had met the minimum requirements in the delamination tests. Furthermore, kelempayan, pulai and merawan had met the minimum test requirements exceptionally well by having 0% of total delamination (Figure 2 & 3) in all tests. This suggests that the three timbers had bonded very well with PRF and were durable enough in withstanding drastic wet-dry condition under the total exposure environment.

Results for bakau showed the otherwise trend. Bakau had barely met the minimum requirement in the boiling water soak test; however, it had successfully met the requirement in the vacuum pressure test. The Student T-test statistical analysis showed that there was no significant difference from the results between vacuum pressure delamination test and boiling water soak test. It is noteworthy that at least half of the bakau test pieces had successfully met the minimum acceptable requirements in both the delamination tests (Figure 2 and 3). This suggests the potential in bakau as a lamination feedstock but require further research for improvement.

The shrinkage value in Table 1 is related to the performance in cyclic delamination. It appeared that the total delamination percentage increased when the shrinkage value of the timber in tangential direction is high. The same observation applies to timbers having high tangential/radial shrinkage ratio. In this case, bakau faired the highest shrinkage ratio between tangential and radial. This can be explained by the phenomenon where higher tangential/radial shrinkage ratio would result higher gradient between the tension and compression set in the timber, therefore resulting greater deformation during the course of drying (Peck E.C., 1957).

Table 2: Average delamination for four selected timber in vacuum pressure test and boiling water soak test.

Vernacular Name	Requirement on Acceptable Total Delamination, %		Average Total Delamination, %	
	Vacuum Pressure	Boiling Water Soak	Vacuum Pressure	Boiling Water Soak
Bakau	2nd cycle ≤ 5% 3rd cycle: ≤ 10%	≤5%	7.28[b]	5.93[b]
Kelempayan			0.00	0.00
Pulai			0.00	0.00
Merawan			0.00	0.00

[b]T-test analysis showed no significant difference at 95% confidence level.

Figure 2: Percentage of number of sample of percentage of total delamination sorted in groups for bakau, kelempayan, pulai and merawan in vacuum pressure test.

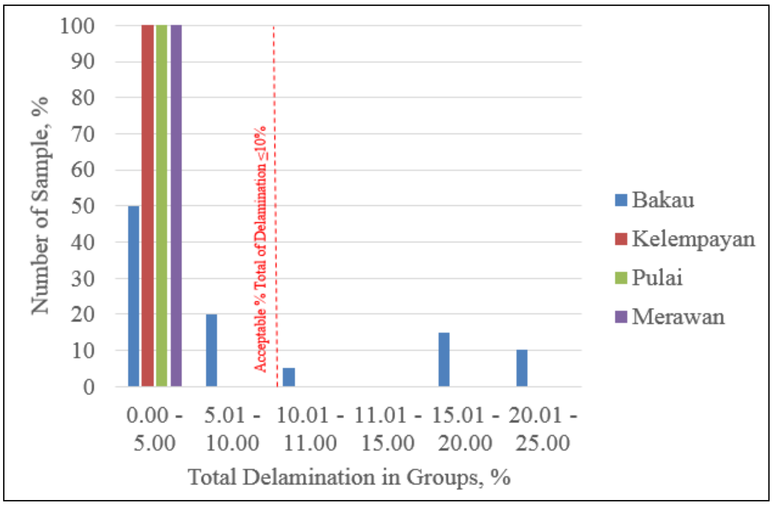


Figure 3: Percentage of number of sample of percentage of total delamination sorted in groups for bakau, kelempayan, pulai and merawan in boiling water soak test.

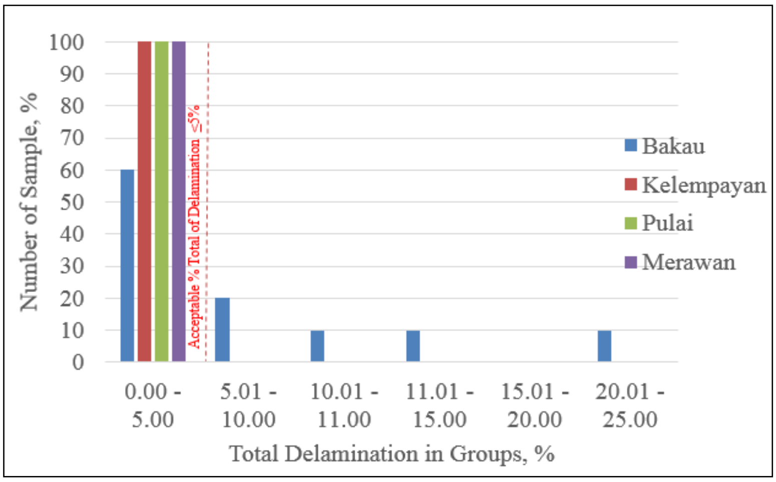


Figure 4: Bakau specimens post vacuum pressure delamination test with mixed of percentage of total delamination.

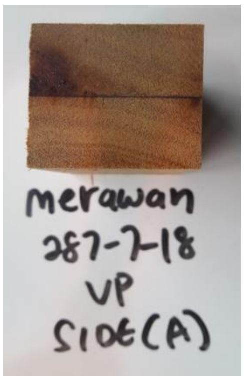


Figure 5: Merawan specimen with no delamination post vacuum pressure test.

The performance of shear strength in glue lines of the selected timbers is summarized in Table 3. According to MS758:2001, shear test can be used interchangeably with delamination test for assessment of the integrity of glue lines. In this study, the results from shear strength test are used as means to countercheck or to complement the results obtained from the delamination tests. The shear strength of glue lines would provide indicator on how well the timber could withstand stress in shear loading; meanwhile, the wood failure percentage enabled the research to gauge an estimation of how well the timber had partaken the adhesive. Nonetheless, the minimum requirement of shear strength of glue lines requires meeting the requirements in pairs - i.e. in the set of shear strength and the corresponding percentage of wood failure.

Results from Table 3 showed that only pulai and merawan had met the minimum requirement of shear strength-percentage of wood failure set. In general, bakau had not performed well in shear loading. Despite that bakau faired the highest average shear strength amongst the four timber type, the acquired high values in shear strength are mainly attributed by its mechanical performance as a solid timber (bakau is classified under the Strength Group A from Strength Group of Malaysian Timbers (Lim S.C., 1991)). The poor bonding performance of bakau can be explained by its low average wood failure percentage, which means it is prone to glue failure. In essence, the bonding between the timber and PRF was less desirable.

As for kelempayan, it had not met the minimum requirements in the shear strength of glue line test. This result is contradictory to the accelerated cyclic moisture resistance tests (Table 2). This finding indicates that both the shear test and delamination test are equally important. Considering that both of the test methods are performed using different mechanism, the accelerated cyclic moisture resistance test provides an insight of how durable the glue lines in the timber in withstanding moisture under the desired level of exposure. As for shear test on dry specimens, the test provides information on the strength of the glue lines. In the case should the two results agree with one another, the results will complement each other and further validates the bonding performance of the species in partaking cum reacting with the adhesive of interest. If the two results are contradictory, this would shed lights to the research direction for area(s) of improvement.

Table 3: Average shear strength and wood failure percentage for four selected timber

Vernacular Name	Minimum Requirement		Average Shear Strength, MPa	Average Wood Failure, %
	Average Shear Strength, MPa	Wood Failure %		
Bakau			16	8
Kelempayan	6	90	7	36
Pulai	8	72	6	93
Merawan	≥11	45	15	82

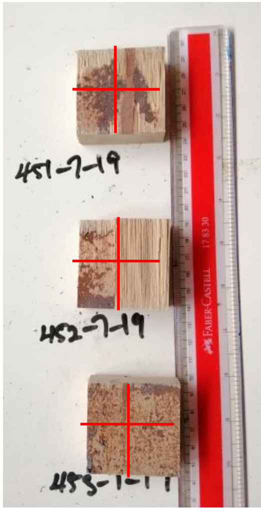


Figure 6: Bakau specimens post block shear test with low percentage of wood failures.

CONCLUSION

In general, the shrinkage values of the tangential/radial ratio appeared to be a strong indicator of the delamination performance of a timber species. As the tangential/radial shrinkage ratio increases, the percentage of delamination increases as well.

Pulai and merawan are suitable to be used as feedstocks for glue lamination. Both the timbers had met the minimum requirements for delamination tests and shear strength for glue lines test. The test results suggest that these timbers are suitable for environment under total exposure. However, consideration on the durability of the solid timber towards pest resistance should be given in relation to the intended use. Appropriate preservative treatments would resolve this concern.

Kelempayan had performed exceptional well in resistanting toward delamination. However, it had not met the minimum requirement in shear strength for glue lines. It is suggested that research initiatives to be taken in value-adding its material properties, in hope that this will improve the timber performance in the shear strength and wood failure percentage set.

Lastly, bakau had not been able to meet the entire tests minimum criterion. Nevertheless, results from the vacuum pressure test and boiling water soak test had showed that at least half of the test pieces had met the respective minimum acceptable requirements (Figure 2 and 3). On this basis, the potential of bakau glue lamination should not be totally omitted. Considering that bakau is from Strength Group A (formerly classified in the Strength group of Malaysian timbers), the potential as a laminated feedstock under appropriate care and utilisation should not be overlooked. Further improvements on the material, such as pretreatment in improving the dimensional stability of bakau could be the way forward for glue lamination.

REFERENCES

Amirah Ali Chew et al. (2016). *Compression strength of composite glulam timber reinforced between first and second, third and fourth lamina*. Jurnal Teknologi 78 (5-4): 49-55.

Anon. (2020). *Hopea (merawan)* (PROSEA). https://uses.plantnet-project.org/en/Hopea_(merawan)_(PROSEA). Archived on 17 Aug 2020.

Choo K.T., Lim S.C., & Gan K.S. (2001). *Timber notes - Medium hardwoods III (mata ulat, mempening, mengkulang, meransi, merawan)*. TTB no. 20. FRIM.

Hamami (1990). *The durability of phenol-resorcinol-formaldehyde glue joints on three Malaysian hardwood species*. Pertanika 13(2), 159-169.

Hazira et al. (2012). *Bending strength of glulam from selected Malaysian hardwood timber*. WCTE Auckland, 15-19 July 2012.

JAS1152 (2007). *Japanese agricultural standard for glued laminated timber*. Japanese Agricultural Standard.

Lim S.C. et al. (2016). *Identification and properties of Malaysian timbers*. Malaysian Forest Records No. 53. FRIM. ISBN 978-967- 0622-60-6.

Lim S.C. (1991). *Malaysian timbers - bakau*. Timber Trade Leaflet No. 115. MTIB-FRIM. ISSN:0127-9254.

MS758 (2001). *Glue laminated timber – Performance requirements and minimum production requirements.* 1st ed.,Department of Standard Malaysia.

Norshariza Mohd. Bhkari et al. (2015). *Assessment in bending and shear strength of glued laminated timber using selected Malaysian tropical hardwood as alternative to timber railway sleepers*. Jurnal Teknologi 78 (5-5): 111-117.

Peck E.C. (1957). *How wood shrinks and swells*. Forest Products Journal, 7(7). Pp. 235-244. Forest Products Research Society, Wisconsin.

Sim H.C. (1982). *Malaysian timbers - pulai*. Malaysian Forest Service Trade Leaflet No. 64. MTIB.

Tan Y.E & Mohd. Zaini U. (1992). *Effects of moisture content and sawing pattern on the gluing of Meranti tembaga (Shorea leprosula)*. Journal of Tropical Forest Science 5(1):44-53