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FEASIBILITY OF BAKAU (*RHIZOPHORA* SPP.) FOR GLUE LAMINATION

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INTRODUCTION

Bakau (*Rhizophora spp*.) is one of the most common species inhabiting in the mangrove forests of Malaysia. In Peninsular Malaysia alone, it has accounted for 15% (103,427 ha) of the mangrove areas in the country. The majority of the Peninsular mangrove distributions can be found in Johor (27,343 ha), Perak (42,269 ha) and Selangor (19,547 ha) (Hamdan et al. 2012).

The designation of the mangrove land status in Malaysia can be widely classified as stateland, or sustainably managed under national plan - Permanent Reserve Forest (PRF). In relation to bakau in PRF management, the scheme has placed re-plantation and sustainable harvesting of bakau (*Rhizophora spp.*) for timber production as one of the management strategies (Hamdan et al. 2012).

In terms of physical properties, the density range of bakau is large: ranging from 630 to 1025 kg/m^3. The species inherits strong mechanical properties with high average Modulus of Elasticity (22 GPa) and Modulus of Rupture (156 MPa). Bakau is classified under strength group A (Lim et al. 2016); nonetheless, it is not listed in the Strength Groups (SG) of Malaysian timbers (MS 229 2009).

Despite its renowned strength performance, the use of bakau wood is considered limited. It is mainly popular for charcoal making (MS229 2009) and fuelwood (Anon. 2017). Considering that the species is sustainably managed, the potential of having sustainable bakau timber supply is promising in current and near future. Thus, FRIM has taken the initiative to introduce value-added products made from bakau timber. Amongst the timber-based products that have been developed are indoor and outdoor furniture, as well as garden pergola (Hamdan 2012). This initiative has led to the present study in exploring the potential use of bakau for structural application. The bonding performance of bakau is discussed in this paper, followed by recommendation on the potential use of bakau in glue lamination.

METHODOLOGY

Bonding performance of bakau wood was assessed using i) the vacuum pressure cyclic delamination test based on MS 758:2001 Method A (MS758 2001) and ii) water boiling test based on JAS 1152:2007 (JAS1152 2007). The intended service for both of the tests was meant for exposure under harsh outdoor environment. In any case, if the result from either test has indicated pass or falling not far from the respective acceptable range of delamination percentages, this suggests that bakau can be opted as a choice for glue lamination.

Fabrication of glulam samples

All bakau woods received were conditioned in a chamber set at 20°C and 55% relative humidity to achieve equilibrium moisture content 12% prior to lamination. Glulam samples were prepared using the

Resorcinol Formaldehyde (RF) adhesive. The clamping pressure was set at 18 kgf/cm^2. Considering there were limited wood supply during the time of fabrication, two-ply glulam samples comprised of 1 glue line were prepared for all cases.

Method and sample preparation

Tests are summarised in Table 1.

Table 1 Type of delamination test and number of replicate

Type of Delamination Test	Test Method Standard	No. of Replicate
i. Vacuum pressure test	MS 758:2001 Method A	20
ii. Boiling water soak test	JAS 1152	20

i. *Vacuum pressure test*

Test pieces were submerged in a vessel that had been vacuumed between 75 and 85 kPa and held for 5 minutes. Subsequently, the vacuum in the vessel was released and a pressure between 500 and 600 kPa was applied for 1 hour. The same process was repeated for the second cycle. 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%. The percentage of delamination was computed using Equation 1.

In the case of delamination of more than 5% in the 2nd cycle, the test specimens were then further subjected to 3rd cycle for determination of the final percentage of delamination. The maximum percentage of delamination was computed using Equation 2.

ii. *Boiling water soak test*

Test pieces were immersed in boiling water for 4 hours and transferred to water at room temperature (10–25°C) for 1 hour. Subsequently, test pieces were dried in an oven at 70±3°C until the mass had reached between 100–110% of the pretest mass. The percentage of delamination was calculated based on Equation 1.

$$\text{Delamination (\%)} = \frac{\text{Total delamination (mm)}}{\text{Total Glue Line (mm)}} \times 100\%$$

… Equation 1

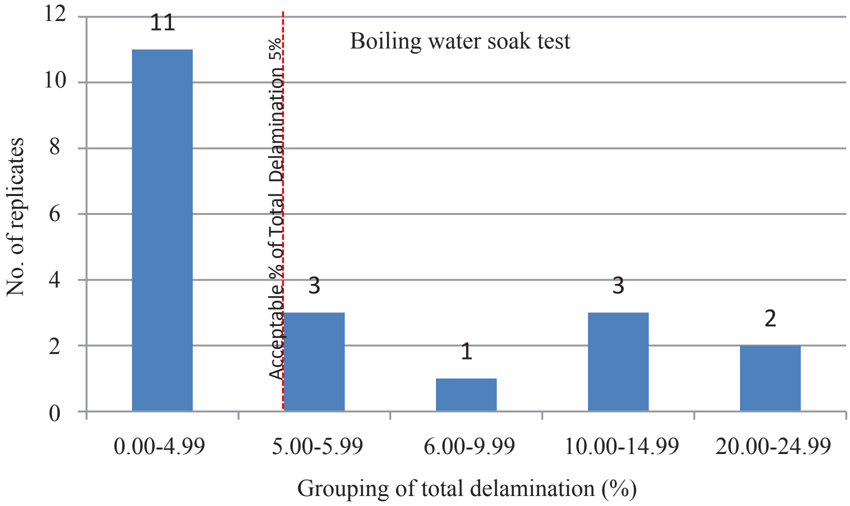
$$\text{Maximum Delamination (\%)} = \frac{\text{Maximum delamination (mm)}}{2 \times \text{Maximum Glue Line (mm)}} \times 100\%$$

… Equation 2

RESULTS AND DISCUSSION

The average moisture content (MC) of bakau wood prior to lamination was 12.73% [SD=0.32]. The average density of the test specimens was 974.85 kg/m^3 [SD=19.62]. As the average MC during the time of test was close to 12.0%, it was unnecessary to do adjustment of densities to 12% MC.

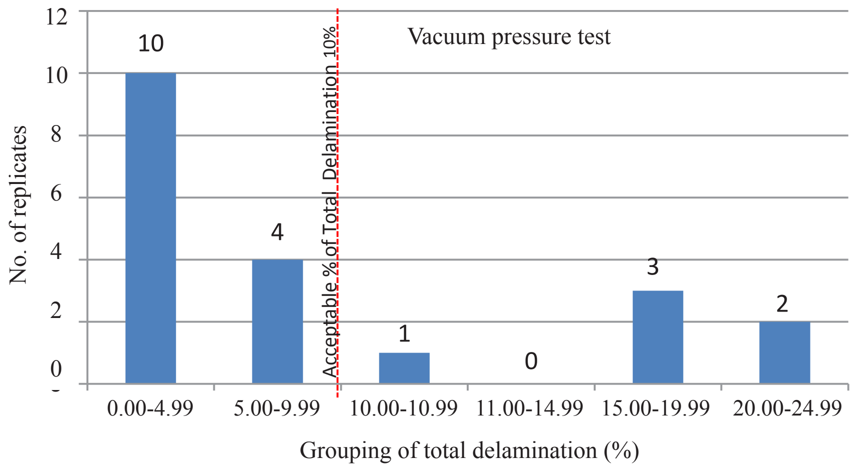
a) Boiling water soak test based on JAS 1152



Graph 1 Sampling distribution from boiling water soak delamination test

Table 2 Summary of delamination test result from boiling water soak delamination test

Descriptions	Percentage %
Average percentage of delamination	5.93 (S.D.=7.30)
Maximum delamination	24.62
Minimum delamination	0.00



Graph 2 Sampling distribution from vacuum pressure delamination test

Table 3 Summary of results from vacuum pressure delamination test

Descriptions	Percentage %
Average percentage of total delamination	7.28 (S.D.= 8.33)
Range: Max.	26.50
Min.	0.00
Average Maximum Delamination of a single glue line	3.64 (S.D.=4.16)
Range: Max.	13.25
Min.	0.00

Based on Graph 1 and 2, test results from vacuum pressure test appeared to be more favourable than that of the boiling water soak test. The total percentage of the "pass" specimens from vacuum pressure test was 70% as compared to boiling water soak test (55%). Despite that the acceptable percentage of delamination from boiling water soak test is more stringent (≤5%) than that of the vacuum pressure test (<10% in cycle number 3), it is known that both of the tests were designed for glulam that are to be exposed under harsh service environment. In the vacuum pressure testing procedure, it required test specimens to undergo at least 2 to 3 cyclics under the specified pressure in MS758:2001. The level of harshness exposed was presumably equivalent to boiling water soak test. The overall results from the two testing methods shall be treated as complementary to one another. Hence, it should be assessed impartially.

On the other hand, the number of test pieces that had failed at the border of acceptable delamination in the boiling water soak test was significant. When this was added-up, the total number of “acceptable” test pieces comprised almost half of the total test population. Considering that both tests were meant for harsh service environment, it was expected that bakau would be able to fair much better when subjected to water soaking test at ambient temperature. Having deduced from both the above justifications, we can conclude that bakau can be laminated well using RF adhesive.

Nonetheless, wood failures were observed in most of the test pieces especially for those from the boiling water soak test. The appearance of checks and splits happened only after oven-dry steps and not after soaking. This brief observation indicated that bakau wood may inherit high shrinkage value resulting with intensive stresses between wood fibres during and after drying - Figures 1(a) & (b). This observation was in line with its drying properties which were known to be prone to surface checkings, end splits, and splits along the pith during post drying (Lim *et al.* 2016). In essence, bakau wood may not be suitable to be used under drastic service condition with high fluctuations in ambient temperature. This also suggests the importance of applying appropriate drying schedule and suitable selection of end-use service condition.

1(a)

1(b)

Figure 1(a) & (b) (a) Some of the test pieces that had undergone vacuum pressure test. (b) Test pieces that had undergone boiling water soak test. Pen marks indicate the length of delamination along the glue line. The photos indicate extensive checks and cracks around the pith instead of delamination.

CONCLUSION

Bakau has shown favourable potential in glue lamination. By glue lamination, various products can be produced in size of much larger than the original size of bakau trees. Engineering applications of bakau glulam has great potential; however, the durability aspect of bakau has to be explored further. In addition, it is not advisable to expose bakau-made glulam products under service condition which endures drastic change in temperature.

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The purpose of the study is to explore the potential of bakau wood for glue lamination. The bonding performances of bakau for outdoor structural application had been assessed and reported in this paper. In general, more than half of the bakau specimens had met the minimum requirements of the selected testing methods. It was observed that the occurrence of cracking was prominent during running of delamination tests. Hence, special drying care and selection of suitable applications are important.

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