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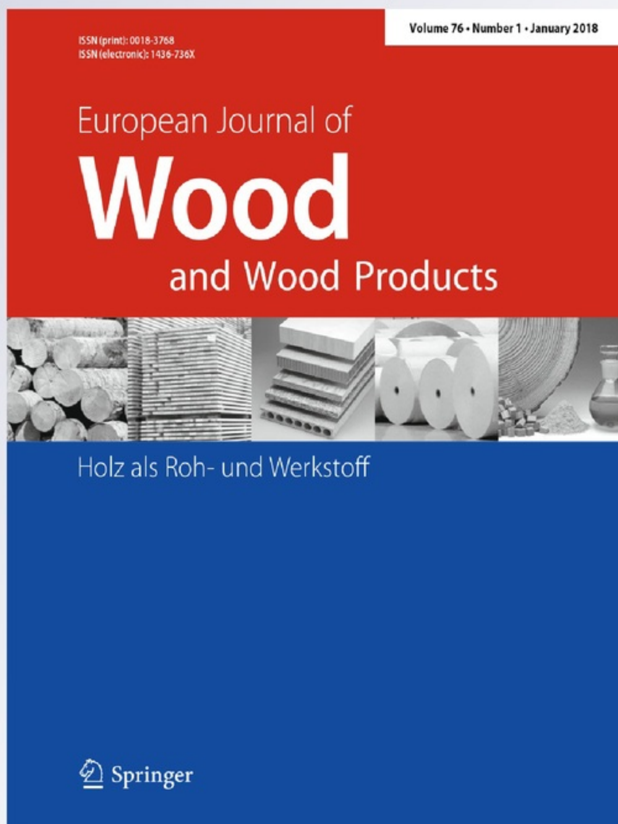

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BRIEF ORIGINAL

Flexural strength properties of glulam made from combining of sago bark and two wood species from West Papua

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Abstract This paper describes the prospect of producing sago bark-glulam in combination with two less used wood species. In total 51 glulam, 17-combined layers with three replications, were tested for flexural strength, density, and delamination. The results show that laminating increased the density compared to that of the original material. Plain sago bark has higher MOR and MOE than when it is combined with the two other species into glulam, with reductions of 8.2 and 43.9%, respectively. Delamination mostly occurred following 24 h of water immersion for the glulam of sago bark and its combinations, but it was absent in glulam without sago bark.

1 Introduction

The scientific name of sago (*Metroxylon sago* Rottb) is derived from metra meaning pith or parenchyma, and xylon, meaning xylem, a palm-producing starch that is endemic to the tropical and sub-tropical area of South East Asia and Oceania (Flach 1997). It is a main source of carbohydrate for people living at coastal areas, and the barks are mainly used for flooring mat (decks), the leaves for roof, and the fronds for walls of traditional-hut houses of the coastal community in South East Asia and Oceania (Awg-Adeni et al. 2010). In South Sorong-West Papua Province, sago has been harvested commercially at industrial scale to produce bioethanol, but their barks were burned in furnace to produce steam for drying purpose and other fibrous residues are left over polluting the environment (Karim et al. 2008). In Malaysia, sago bark is one of the solid residues and occupies approximately 17% of total volume of processed logs (Awg-Adeni et al. 2010).

To maximize the utilization of sago bark and produce a residual-based and ecofriendly material, sago barks are processed into glue-laminated beams (glulam), and a trial has been designed to combine it with other less used wood species of Pulai (*Alstonia scholaris*) and Binuang (*Octomeles sumatrana*). These species are lightwoods that are mostly used for packaging and pallet purposes (Wahyudi et al. 2014). Manufacturing glulam in combination with two less used wood species could presumably improve mechanical properties, and enlarge utilization. Glulam has been widely used for numerous applications including arches of airplane hangers, timber for floors, dome structures, timber bridge decks (Zang et al. 2011). Therefore, this research is designed to investigate the feasibility of making glulam from sago bark basis and to test their flexural strength, modulus of rupture (MOR) and modulus of elasticity (MOE), including density and delamination test.

2 Materials and methods

2.1 Materials and their preparation

Uncultivated sago with diameter at breast height (DBH) of 55 cm from Andai Village Manokwari was used. Chain saw (Stihl 070, Germany) was employed to cut off and divide the sago trunk into a length of 900 mm, and to peel out the barks with round peeling. Initially, the sago barks have net dimensions of 900 mm × 100 mm × 30 mm (length × width × thickness), and are then processed into final dimensions of 400 mm × 46 mm × 12 mm. Boards of 4 m × 0.2 m × 25 mm of Pulai and Binuang wood species

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were supplied from local sawn timber retailer, and finally processed into dimensions of 400 mm × 50 mm × 20 mm. All materials were kept at room condition, 27 °C and 84% relative humidity (RH), for 14 days to attain air dried-moisture contents. Sample preparations were conducted with hand planner (Makita N1900B, Japan), and circular saw (Makita 5800NB, Japan). Sand paper was used to smoothen material surfaces. White glue of polyvinyl acetate (Fox, Indonesia) was used for gluing. Locally made wooden clamps were used for curing the glulam.

2.2 Glulam manufacturing

Three layers of homogenous and combined glulam from sago bark, Pulai and Binuang, and their combinations like Sago-Pulai-Sago were manufactured. Glue spreading was applied with a flat wooden stick at an average rate of spreading of 0.19 g/cm^2 to both surfaces and dried in air-dried condition. To assemble the glulam, the glued layers were arranged parallel to grain direction and placed at the wooden clamp, manually fastened and left to cure for 24 h. 17 glulam regimes were manufactured, such as Sago (SSS), Pulai (PPP), and Binuang (BBB) glulam, Sago-Pulai-Sago (SPS) glulam, Sago-Sago-Pulai (SSP), Pulai-Sago-Pulai (PSP), Sago-Sago-Binuang (SSB), Sago-Binuang-Sago (SBS), Binuang-Sago-Binuang (BSB), Sago-Binuang-Pulai (SBP), Sago-Pulai-Pulai (SPP), Sago-Binuang-Binuang (SBB), Pulai-Binuang-Pulai (PBP), Binuang-Pulai-Binuang (BPB), Binuang-Pulai-Pulai (BPP), Pulai-Binuang-Binuang (PBB), and Pulai-Sago-Binuang (PSB). Each glulam regime has three replications and produced 51 glulam in total.

2.3 Moisture content and density

Moisture content (MC) was determined in air-dried condition (MC %) and density is expressed in (g/cm^3).

2.4 Flexural bending

Flexural strength consists of modulus of rupture (MOR) and modulus of elasticity (MOE), and both are expressed in Giga Pascal (GPa). A 10-tone local-made Universal Testing Machine was employed for testing. Three replicates were applied to each sample. The tests were conducted at the Laboratory Structure and Mechanical of Civil Engineering, Faculty of Engineering, Gadjah Mada University. Flexural bending test (British Standard BS 373, 1957) was applied to the width of the glulam, as illustrated in Fig. 1a.

2.5 Delamination test

Delamination tests were conducted according to Japanese Agricultural Standard (JAS) for Glued Laminated Timber Notification No. 234, 2003 to evaluate gluing performances by immersion method using distilled water. After 24 h immersion, delamination was examined and expressed in percent (%) to surface areas of the samples.

3 Results and discussion

3.1 Density

Virgin sago bark has density of 1.07 g/cm^3 and its density was increased to 1.12 g/cm^3 when sago barks were manufactured into three layers of glulam (Table 1). Similarly, density of both less used wood species of Pulai and Binuang are improved either manufactured into homogenous layers or combined beams. Density of the less used wood species of Binuang and Pulai could be increased significantly when these wood species were combined with sago barks into glulam. For example, glulam made of Pulai, and glulam Sago-Pulai has density of 0.37 and 0.61 g/cm^3, respectively. Similarly, it also applies to the glulam of Sago-Binuang, and Sago-Binuang-Pulai, as illustrated in Table 1. Having

(a) (b) (c) (d)

Fig. 1 Series of flexural bending test (**a** bending test) and glulam failure occurred (**b** permanent bending of sago glulam, **c** delamination of glued-line of Sago-pulai-Sago glulam, **d** failure occurred on Pulai-pulai sago glulam)

Table 1 Density of sago bark, Pulai, Binuang and their laminated beams manufactured

No	Material	Density (g/cm^3)	Flexural bending (GPa)		Delamination (%)
			MOE	MOR	
Wood					
1	Sago bark	1.07	22.09	0.25	–
2	Pulai	0.34	13.74	0.10	–
3	Binuang	0.38	14.36	0.08	–
Glulam					
1	SSS	1.12	20.28	0.14	65
2	PPP	0.37	10.30	0.06	0
3	BBB	0.31	2.24	0.03	0
4	SPS	0.70	12.30	0.06	33
5	SSP	0.71	8.47	0.05	75
6	PSP	0.50	3.19	0.04	17
7	SSB	0.66	12.7	0.04	100
8	SBS	0.76	18.63	0.08	67
9	BSB	0.51	3.37	0.05	50
10	SBP	0.47	4.55	0.04	60
11	SPP	0.51	3.67	0.05	50
12	SBB	0.45	4.62	0.06	7
13	PBP	0.35	3.22	0.04	0
14	BPB	0.34	3.12	0.04	0
15	BPP	0.48	1.85	0.04	0
16	PBB	0.36	2.45	0.04	0
17	PSB	0.47	2.84	0.04	83

density more than 1 g/cm^3, sago bark and its glulam could be classified into densified material. This material is quite difficult to be managed for its woodworking properties, and naturally, these barks have irregular alignment (Fig. 1b) accompanied by heavy intensity of vascular bundle that make this material difficult to be planed for creating smoothness and flatten the surfaces.

3.2 Flexural strength

A single layer sago bark has the highest flexural strength both for MOE and MOR, 22.09 and 0.25 GPa, respectively (Table 1). However, when the sago barks are manufactured into glulam their flexural bending was decreased slightly by 8.2% for MOE and 43.9% for MOR. Similarly, when two less used wood species are manufactured into glulam, either homogenous or combined, their flexural strengths were reduced significantly in comparison to the single layer of Pulai and Binuang, respectively. During flexural bending test, glue-line failures did not occur in sago bark glulam (Fig. 1b), meaning that the glue-line produced with the wooden clamp is good enough to resist shear between the lamina. It was also applied to the glulam of Binuang and Pulai. Glulam failures of the combined glulam of wood and sago varied, ranging from glue-line delamination (Fig. 1c) to wood splitting (Fig. 1d).

Sago glulam has higher flexural strength properties than pine (*Pinus merkusii*) with 0.65 g/cm^3 density, 8.18 GPa for MOE and, 0.04 GPa for MOR, respectively (Lestari et al. 2015). On the other hand, flexural strength of Pulai and Binuang both for MOE and MOR are lower than those of a three layer homogenous glulam made from two tropical fast-growing wood species using mahogany tannin adhesive, Jabon (*Anthocephlus cadamba*) and Sengon (*Falcataria moluccana*) reported by previous researchers. They also reported that Jabon (0.37 g/cm^3) produces 4.75 GPa MOE and 0.24 GPa MOR and Sengon (0.29 g/cm^3) has 4.99 GPa MOE and 0.194 GPa MOR.

4 Delamination test

Glulam made either from sago bark or its combinations dominantly failed for delamination test after 24 h of water immersion. An average of 56% delamination is substantially higher than 5% delamination maximum of JAS. On the other hand, the glulam from two less used species and their combinations passed. Delamination occurred probably due to the densified sago bark as the glue could not penetrate into the cell cavities. This means that the glulam made from moderate to higher density has failed to fulfill the minimum standard of delamination test. Pine-glulam glued with mahogany tannin adhesive has a delamination ratio of 30% following cold-water immersion, while glulam of Jabon and Sengon glued with similar adhesive regime have 1.5 and 0% delamination (Lestari et al. 2015).

5 Conclusion

Densified material of sago bark was successfully manufactured into glulam, either in homogenous beams or combined with two less used wood species. Their flexural strengths of the single layer sago bark are higher than those of their sago glulam. However, the glulam consisting of sago barks seriously failed the delamination test following 24 h water immersion, and the glulam made of two less used wood species successfully passed the delamination test. Therefore, the prospect of sago bark utilization for glulam products for interior purposes is wisely possible whether it is in homogenous beams or combined with less used wood species.

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Compliance with ethical standards

Conflict of interest The authors have declared that they have no conflicts of interests.

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