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Properties of single-layer urea formaldehyde particleboard manufactured from commonly utilized malaysian bamboo (*Gigantochloa scortechinii*)

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Abstract—*Gigantochloa scortechinii*, one of the most widespread bamboo species in Peninsular Malaysia was investigated for its suitability as a raw material for particleboard production. A total of 120 bamboo culms from three different age groups (1-, 2- and 3-yr-old) were harvested from managed bamboo clumps in FRIM. The bamboo particles produced from the flaking process were used in the making of single-layer urea formaldehyde particleboard. The particleboards produced were then tested for their mechanical properties and dimensional stability according to British Standard Methods. The results of the tests showed that age, resin content and board density significantly affected the single-layer particleboard properties. Irrespective of bamboo age, particles of *Gigantochloa scortechinii* are suitable materials for the manufacture of urea formaldehyde particleboards.

Key words: Bamboo; particleboard; urea; resin; board properties.

INTRODUCTION

Malaysian bamboos are classified as a minor forest product and are traditionally considered as a weed interfering with the normal regeneration, development and maintenance of the main timber species [1–3]. In the past, attempts were made to control their growth but now, due to the rapid expansion of bamboo-based industries, they have become the second most important non-timber produce in Malaysia after rattan [4]. They played an important role in the lives of the local people, particularly those in the rural areas and are usually being used for making

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basket-ware, cords and toys, furniture and houses. The bamboo industry has developed into a multi-million dollar industry with its products enjoying very high demand domestically as well as internationally. However, in producing the various products, much bamboo waste is generated [5], excluding that which is discarded during harvesting and transporting; if no action is taken, the bamboo industry is heading towards collapse. Therefore, the optimum use of this resource lies in the production of reconstituted products such as particleboard.

At present, rubberwood is the most abundant material for particleboard manufacture in Malaysia. Since rubberwood is also a highly sought after material for the development of the furniture industry in the country, other lignocellulosics materials have to be conserved to overcome the danger of a deficiency of this excellent material in the near future. In the context of the increasing shortfall of industrial wood, emphasis should be given to the development of non-wood materials, especially bamboos. In Malaysia, bamboos have a widespread distribution and rapid rate of growth. Due to their inherent, unique physico-mechanical properties, they can be utilized in higher value-added applications by transforming the raw material into high quality products using modern processing techniques. Bamboo composite is one such product. In this context, the development of bamboo particleboard is of immediate interest, as the pressure on wood supply could be reduced to some extent. This is particularly relevant, as the raw material can be made available at a faster rate because bamboo can be harvested in a 3 to 5 year cycle as against 15–20 years for plantation species.

With the abundance of the bamboo resource that is currently being underutilized, as well as the need to improve the properties and development of panel products, particleboards offer tremendous potential and opportunities. This paper highlights the properties of single-layer urea formaldehyde particleboard produced from *G. scortechinii*. The effects of age, board density and resin content on the board properties are discussed.

MATERIALS AND METHODS

Raw material collection and preparation

Forty culms each from 1-, 2- and 3-yr-old *G. scortechinii* were obtained from the bamboo plantation of Forest Research Institute of Malaysia (FRIM), Kepong, Selangor. All branches present were removed and the clean culms were subjected to longitudinal splitting. The bamboo splits were then fed into a Pallman drum chipper. The chips produced were then flaked in a Pallman knife-ring flaker and the particles produced were screened into 0.5, 0.5–1.0, 1.0–2.0 and >2.0 mm sizes before being oven-dried at 60°C to a moisture content of about 5%.

Determination of initial moisture content and oven-dry density

Ten bamboo samples with dimensions of 2 × 3 cm × thickness taken from the middle section of the first internode were selected randomly. The initial moisture content was determined by weighing the initial weight followed by oven drying in an oven at 105°C for 24 hours and then taking its final weight. The difference between the two divided by the oven-dry weight multiplied by 100 gave the initial moisture content. The oven-dry density was determined by dividing the oven-dry weight by its green volume. Abd. Latif Mohmod *et al.* [6] have reported the fiber and chemical properties.

Particleboard manufacture

In the making of single-layer particleboard of 12 mm thickness at three density levels (561, 641 and 721 kg m^{-3}) and resin contents of 8, 10 and 12%, a measured quantity of flakes was sprayed with a resin mix containing urea–formaldehyde, hardener and water within a glue blender. The resin used in the study was the same as those being used in the Malaysian wood particleboard industry. If this application was successful, then no new formulation would be required. The particles used consists of 60% of 1.0–2.0 mm, 30% of 0.5–1.0 mm and 10% of >2.0 mm particle size. The sprayed particles were then laid in a wooden mould and pre-pressed at 3.5 MPa for about 30 seconds. The consolidated mat was finally pressed for 6 min at 160°C in a Taihei hot-press. Three boards were produced at each manufacturing variable.

Board evaluation

The strength and dimensional properties, namely, thickness swelling (TS), water absorption (WA), modulus of rupture (MOR) and modulus of elasticity (MOE), internal bond (IB) and screw-withdrawal (SW) were tested according to the British Standard: BS EN [7] and results compared with BS 5669 [8].

RESULTS AND DISCUSSIONS

Moisture content and oven-dry density

The average initial moisture content and oven-dry density according to age group are given in Table 1. Highest moisture content (MC) was observed in 1-year-old bamboo while the lowest in the 3-year-old bamboo. The decreased in MC with age according to Abd. Latif *et al.* [9] could be related to its growth establishment, such as the development of branches and leaves.

Table 1 also shows that 3-year-old bamboo has the highest oven-dry density (0.75 g cm^{-3}) while 1-year-old bamboo the lowest density (0.60 g cm^{-3}). Espiloy [10] and Jamaludin *et al.* [11] also found a similar pattern of density variation.

Table 1.
Initial moisture content and oven-dry density according to age group

Age (yr)	Initial moisture content (%)	Oven-dry density ($g\,cm^{-3}$)
1	96.95	0.60
2	91.08	0.63
3	72.58	0.75

According to Liese [12] this behaviour is due to the decrease in parenchyma cells and a higher frequency of vascular bundle ditribution.

Strength and dimensional properties

The strength and dimensional properties of single-layer particleboard are shown in Table 2.

All boards produced with a minimum resin content of 8% at a board density of 641 $kg\,m^{-3}$ were able to meet the minimum strength requirements of BS 5669. Boards made from one year-old bamboo particles with a 12% resin and a density of 721 $kg\,m^{-3}$ were observed to possess the highest values of MOR (28.52 MPa) and MOE (3613 MPa); two year-old bamboo had the highest IB (1.11 MPa) while three year-old had the highest SWS (957 N) and SWE (676 N) values. In general, bamboo particleboards produced at the age of one year-old and older, and with the combination of more than 8% resin content (board density >641 $kg\,m^{-3}$), surpassed the minimum strength requirements of the BS. However, only boards produced from one-year-old bamboo at a density of 561 $kg\,m^{-3}$ and a resin content of 12% was able to meet the TS requirements of 8.0%. All other boards failed to do so.

The summary of analysis of variance (ANOVA) on the effects of age, resin content and board density on the particleboard properties are shown in Table 3. All the main variables of age, density and resin have significant effects on all the board properties.

Age had a significant effect on all the board properties (Table 4). An earlier study by the authors on the particleboard from *Bambusa vulgaris* also found a similar pattern [13]. Correlation analysis (Table 5) further revealed that the WA and MOR decreases insignificantly, while MOE and TS increases insignificantly with age. However, the strength properties of IB, SWS and SWE were observed to increase significantly with age. The adhesive spread per unit area of the particles could be the controlling factor on the effect of age on the strength and dimensional properties of particleboard [14]. Bamboo particles from any age group seem to be suitable for the manufacture of single-layer particleboard.

Increments of resin contents showed significant effect on all the board properties (Fig. 1). The correlation analysis also indicates that MOR, IB, SWS and SWE increase significantly while WA and TS decreases with an increase of resin content. With more resin available at higher resin content, more bonding sites are made available, thus improving the strength properties and increased their dimensional stability, significantly. Other works on the strength properties–resin c[illegible]

Table 2.
Physical and strength properties of single-layer UF particleboards

Age (yrs)	Resin (%)	Density (kg m^{-3})	MOR (MPa)	MOE (MPa)	IB (MPa)	SWS (N)	SWE (N)	WA (%)	TS (%)
1	8	561	9.18	1598	0.23	182	137	38.48	10.77
	10		9.91	1675	0.32	215	163	36.41	8.50
	12		11.32	1734	0.44	249	169	34.22	7.31
	8	641	15.83	2480	0.39	539	417	63.57	24.46
	10		20.21	2759	0.59	458	461	51.89	13.84
	12		18.03	2649	0.67	598	526	49.39	11.57
	8	721	21.33	3059	0.50	535	458	52.31	23.88
	10		24.40	3330	0.68	684	545	42.91	15.08
	12		28.52	3613	0.69	719	622	36.33	12.42
2	8	561	9.77	1759	0.39	307	223	49.07	16.39
	10		11.72	1896	0.51	358	275	41.27	11.96
	12		13.37	2083	0.61	405	325	36.00	7.60
	8	641	17.87	2891	0.66	542	428	59.89	22.18
	10		20.98	3071	0.78	583	497	53.80	16.21
	12		21.04	2989	0.94	711	549	45.94	13.40
	8	721	17.37	2542	0.77	656	484	48.38	20.45
	10		23.94	3214	0.99	788	616	40.20	15.17
	12		22.04	3132	1.11	747	655	36.85	11.54
3	8	561	11.56	1985	0.48	489	358	52.68	17.16
	10		12.52	1959	0.45	476	376	45.75	11.07
	12		13.68	2168	0.67	531	381	34.93	9.17
	8	641	17.05	2538	0.58	629	459	46.43	17.81
	10		17.95	2684	0.72	558	497	39.52	11.60
	12		19.12	2913	0.86	663	471	34.09	10.55
	8	721	18.28	2696	0.71	724	576	42.40	20.94
	10		20.21	2934	0.88	803	574	37.16	12.69
	12		24.16	3544	1.04	957	676	34.05	11.80
BS 5669			min 13.8	min 2000	min 0.34	min 470	min 360	n.a	max 8.00

Notes: MOR — Modulus of rupture, MOE — modulus of elasticity, IB — internal bond, SWS — screw withdrawal surface, SWE — screw withdrawal edge, WA — water absorption, TS — thickness swelling.

relationship on particleboard manufactured from wood [14–16], bamboo [17] and oil palm empty fruit bunches [18] also found a similar trend.

The strength and dimensional properties of particleboard are directly influenced by board density [14]. This is particularly true since higher density is usually associated with higher strength properties. Figure 2 shows that all the MOR, MOE, IB, SWS and SWE values increase with linear increase in board density. The increase in strength properties may be associated with higher compaction ratio at higher density. Other researchers also reported the same trends [17–20]. Table 5

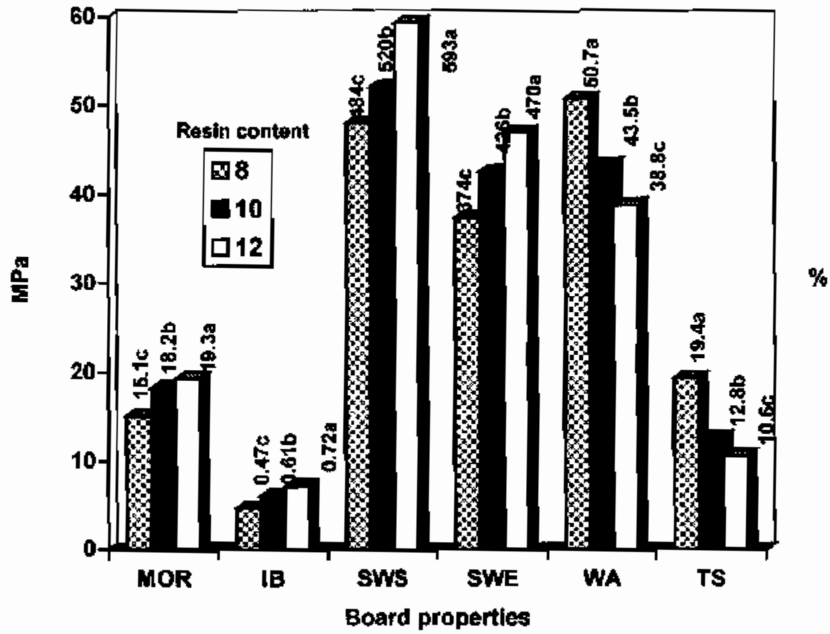

Figure 1. Effects of resin content on the mechanical properties.

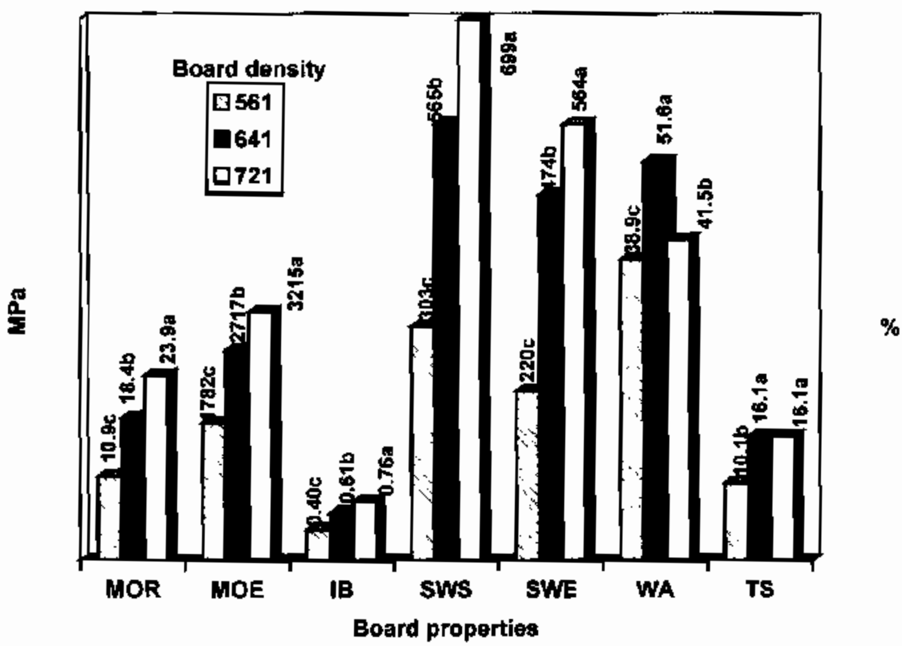

Figure 2. Effects of board density on the board properties.

Table 3.
Summary of the analysis of variance on the board properties

SOV	Df	MOR	MOE	IB	SWS	SWE	WA	TS
Age (A)	2	8.95*	3.2E6**	0.87**	3.6E5**	1.2E5**	216.9**	22.58**
Density (D)	4	1668.3**	2.2E7**	1.37**	1.6E6**	1.4E6**	1972**	514.7**
Resin (R)	8	197.60**	1.6E6**	0.66**	1.3E5**	1.0E5**	1517**	888.6**
A × D	4	58.30**	6.5E4**	0.00 ns	3.3E4**	2.9E4**	443**	43.15**
A × R	4	6.81*	1.0E5**	0.32**	5122 ns	5014 ns	13.48 ns	2.65 ns
D × R	4	10.64**	0.00 ns	0.01 ns	3.6E4**	1.1E4**	16.23 ns	53.76**
A × D × R	8	0.77 ns	0.00 ns	0.01 ns	5124 ns	1806 ns	46.78 ns	15.24**

ns — not significant, *significant at $p < 0.05$, **highly significant at $p < 0.01$.

Table 4.
Summaries of the DMRT t-tests on the effects of age on the board properties

Age (yr)	MOR (MPa)	MOE (MPa)	IB (MPa)	SWS (N)	SWE (N)	WA (%)	TS (%)
1	17.50 b	2524 b	0.51 c	473 c	389 b	44.78 a	13.96 b
2	18.31 a	2708 a	0.78 a	592 b	472 a	46.16 a	15.36 a
3	17.17 b	2602 b	0.71 b	648 a	485 a	40.78 b	13.65 b

Note: means having the same letter down the column are not significantly different at $p < 0.05$.

Table 5.
Correlation coefficients of age, density and resin on the board properties

SOV	MOR	MOE	IB	SWS	SWE	WA	TS
Age	−0.01 ns	0.07 ns	0.43**	0.37**	0.25**	−0.13 ns	0.003 ns
Density	0.87**	0.89**	0.64**	0.79**	0.83**	0.11 ns	0.46**
Resin	0.29**	0.23**	0.45**	0.22*	0.23**	−0.48**	−0.67**

SOV — source of variance, ns — not significant, *significant at $p < 0.05$, **significant at $p < 0.01$.

also shows that board density have high significant correlation with the strength properties. However, the increase in board density also leads to higher TS due to more space available among the bamboo particles, which makes it more porous.

CONCLUSIONS

In the manufacture of single-layer particleboard, age, resin content and board density are found to significantly affect the board properties. Particleboards produced from all age groups at a density of over 641 $kg\,m^{-3}$ and at all resin contents are able to meet the strength requirements of the BS 5669. It is expected that with 1% wax addition the WA and TS would be greatly reduced.

In the correlation analysis of the properties of single-layer particleboard, age was positively correlated with IB, SWS and SWE; board density was found to be uncorrelated with WA, while resin content was positively correlated with all the strength properties but negatively correlated with the dimensional properties.

In general, the bamboo particles of *G. scortechinii* are suitable for particleboard manufacture in terms of its strength properties. However, the high 24-hour TS would warrant further studies to be conducted to reduce it to an acceptable level before this species could be used for particleboard production.

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