IMPROVING THE DIMENSIONAL STABILITY OF MULTI-LAYERED STRAND BOARD THROUGH RESIN IMPREGNATION

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PARIDAH, M. T., ONG, L. L., ZAIDON, A., RAHIM, S. & ANWAR, U. M. K. 2006. Improving the dimensional stability of multi-layered strand board through resin impregnation. Three- and five-layered strand boards were fabricated using *Acacia mangium* strands bonded with specially formulated low molecular weight phenol formaldehyde (LPF) resin. The mean density of the boards was 650 kg m^{-3}. The aim of this study was to evaluate the effectiveness of pre-treatment of wood strands with LPF resin to improve the dimensional stability of strand board. The LPF resin was impregnated into the green wood strands prior to spraying with conventional phenol formaldehyde (PF). The furnish was dried by blowing hot air onto the strands to moisture contents between 10 and 11%. The amount of PF resin was fixed at 5% and that of LPF, at 2, 5 and 7% resin solids based on oven-dry weight of wood strands (w/w). The mechanical properties and dimensional stability of the panels were affected by both the amount of LPF resin incorporated as well as board structure (three- and five-layered). The LPF pre-treatment successfully reduced the thickness swelling of the strand board by > 20%, but the internal bond strength obtained was found to be of inferior grade and the curing time needed to be extended by 25%. The study showed that the dimensional stability and mechanical properties of the strand board could be improved through initial impregnation of wood strands with 7% LPF resin and consolidated at 175 °C for at least 10.5 min press time.

Keywords: Low molecular weight phenol formaldehyde, stability, thickness swelling, pretreament

PARIDAH, M. T., ONG, L. L., ZAIDON, A., RAHIM, S. & ANWAR, U. M. K. 2006. Memperbaiki kestabilan dimensi papan stren berlapis melalui rawatan resin. Papan stren tiga lapis dan lima lapis dihasilkan menggunakan stren *Acacia mangium* yang direkat dengan resin fenol formaldehid formulasi khas yang mempunyai berat molekul rendah (LPF). Purata ketumpatan papan stren ialah 650 kg m^{-3}. Tujuan kajian ini adalah untuk menilai keberkesanan rawatan awal stren kayu dengan resin LPF bagi memperbaiki kestabilan dimensi papan. Stren kayu basah dirawat dengan resin LPF sebelum disemburkan dengan perekat fenol formaldehid (PF) biasa. Campuran ini dikeringkan dengan mengalirkan udara panas ke atas stren sehingga mencapai kandungan lembapan antara 10% hingga 11%. Kandungan perekat PF ditetapkan pada 5% manakala perekat LPF pada 2%, 5% dan 7% resin pejal berasaskan berat kering ketuhar (w/w) stren kayu. Ciri-ciri mekanik dan kestabilan dimensi papan stren dipengaruhi oleh jumlah LPF yang digunakan dan struktur papan yang dihasilkan (tiga lapis atau lima lapis). Walaupun rawatan awal dengan LPF berjaya mengurangkan pembengkakan ketebalan papan stren sebanyak > 20%, kekuatan ikatan dalamannya amat lemah dan memerlukan tambahan tempoh pematangan sebanyak 25%. Kajian ini menunjukkan bahawa kekuatan dan kestabilan dimensi papan stren dapat ditingkatkan melalui rawatan awal dengan resin LPF sebanyak 7% pada tekanan 175 °C selama sekurang-kurangnya 10.5 min.

Introduction

Oriented Strand Board (OSB) is usually intended for use in building construction and is most likely to be exposed to environments with varying relative humidities for a long period of time. A major factor restricting the substitution of OSB for plywood in certain applications such as concrete formwork, and floor and roof sheathings is its greater thickness swelling (Geimer *et al.* 1998). Unlike OSB, plywood is manufactured at low pressures of 500 to 700 kPa.

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Hence it sustains relatively little wood cell damage and swells in a manner similar to that of normal wood—from 6 to 12% between oven-dry and saturated conditions. On the other hand, OSB is pressed at much higher pressures, i.e. from 4000 to 6000 kPa, resulting in severe compression and crushing of wood cells. As the cell wall absorbs water under high moisture conditions, the collapsed cells tend to regain their original shape, resulting in thickness swelling of up to 35% in saturated conditions (Dwianto *et al.* 1996, Geimer *et al.* 1998). Hence, improved technology that enhances moisture resistance and reduces thickness swelling is necessary to allow wood strand-based panels to replace plywood in many applications.

Hygroscopicity, swelling and susceptibility of wood to biodegradative organisms can be reduced by impregnating the wood fibres/particles with phenol formaldehyde (PF) resin. Haygreen and Gertjejansen (1971) found that by impregnating 10% low molecular weight PF resin into green particles prior to applying the conventional 5% PF resin reduced the thickness swelling of the particleboard by 86% and thickness springback by about 95%. Low molecular weight resins with active alcoholic groups and less alkalinity have great potential to be used as bioactive polymers for producing dimensionally stable and durable wood materials at low resin loadings (Ryu *et al.* 1993, Dwianto *et al.* 2000). Apart from dramatic reduction in the rate of swelling, Kajita and Imamura (1991) also discovered marked improvements in internal bond strength with increasing impregnation levels.

In this study, low molecular weight phenol formaldehyde (LPF) resin impregnation method was chosen for the development of dimensionally stable multi-layered strand board. Such treatment has been reported (Wang *et al.* 2000) to improve not only the dimensional stability of solid wood but also of composite panels. The main objective of this study was to develop a dimensionally stable multi-layered strand board made from *Acacia mangium* by impregnating the wood strands with LPF resin.

MATERIALS AND METHODS

Acacia mangium logs were cut into billets, debarked and fed into a disc flaker to generate wood strands. The strands were screened where only those of sizes 10–30 mm were accepted. The undersized strands (5– < 10 mm size) and fines (< 5 mm) were ground to generate fine particles of < 1 mm in size and used as the material for surface (top and bottom) layers of the five-layered strand board.

The wood strands were blended with PF (5% w/w) in a rotary drum mixer for those untreated controls while for the LPF-pretreated boards, the LPF resin (at either 2, 5 or 7% w/w of oven-dried weight of wood strands) was first sprayed onto the wood strands and mixed in a rotating blender for 5 min to allow the LPF resin to penetrate into the wood cell wall. Sufficient penetration was achieved when the wood surface felt dry (i.e. all the resin has been absorbed into the wood cells). The moisture content of the furnish at this stage was not controlled which depends on the amount of LPF resin used. The normal PF resin (having 52.5 of solids) was then sprayed onto the furnish at 5% resin content (w/w of oven-dried wood strands) and blended for a further 10 min.

The furnish was dried by blowing hot air onto the strands to moisture contents between 10 and 11%. A total of 24 boards (2 board structures × 4 resin levels × 3 replications) of dimension 12 × 400 × 400 mm and of target density 650 kg m^{-3} were formed manually by laying the strands uniformly through the slits into the former, so that they fell in the same parallel direction. In the three-layered board, the strands in each layer were arranged adjacently with those in the next layer. For five-layered board, small wood particles (< 0.5 mm size) were placed at the additional top and bottom layers of the three-layered mat. Each surface contained approximately 12.5% (w/w) of fine layers. The mat was then cold pressed at 10 kgf cm^{-2} for 2 min, followed by hot pressing at 50 kgf cm^{-2} and an elevated temperature of 175 °C for 7.5 min.

The boards were conditioned at 65% RH and 25 °C and evaluated for bending strength, stiffness, internal bonding, thickness swelling and water absorption in accordance with the Japanese Industrial Standard A 5908 (Anonymous 1994). The thickness swelling (TS) is expressed as percentage of increasing thickness to the original thickness. The expansion ratio in thickness due to water absorption was calculated as:

$$\text{Expansion ratio in thickness due to water absorption (\%)} = \frac{(t_2 - t_1) \times 100}{t_1}$$

where

t_1= thickness (mm) before water absorption

t_2 = thickness (mm) after water absorption
The percentage of water absorption was calculated as follows:

$$\text{Water absorption (\%)} = \frac{(A_1 - A_0) \times 100}{A_0}$$

where
A_1 = weight (g) after water absorption
A_0 = weight (g) before water absorption
The anti-swelling efficiency (ASE) was calculated as follows:

$$\text{ASE (\%)} = \frac{(S_i - S_c) \times 100}{S_c}$$

where
S_i = thickness swelling of impregnated sample
S_c = thickness swelling of control sample

RESULTS AND DISCUSSION

Board density and equilibrium moisture content (EMC)

The density of the three- and five-layered strand boards varied from 719 to 762 kg m^{-3} and 692 to 749 kg m^{-3} respectively (Table 1). The three-layered strand board had an average board density of 740 kg m^{-3} while the five-layered board had 715 kg m^{-3}. The values were respectively 14 and 10% higher than the targeted density of 650 kg m^{-3}. The high variation in board density may be caused by the way the wood strands was being laid where some of the wood strands tended to overlap with each other which happened more at the middle than at the edges of the board. This created uneven distribution of wood strands across the thickness of the board which led to a density variation. Generally, pretreatment of strands with LPF resin resulted in an increase in panel density with an increment parallel to that of the amount of LPF used. The increment was more gradual in the three-layered board compared with the five-layered. Apparently, the presence of fine particles in the five-layered board was not able to reduce the variation in board density.

The average EMC of conditioned panels ranged from 9.4 to 10.5% (Table 1). Relatively high EMC (10.5%) was recorded for the three-layered strand board impregnated with 2% LPF followed by five-layered control board (10.2%). The EMC of the strand board decreased significantly as the amount of impregnated LPF increased. The EMC of the boards was found to be significantly lower for boards impregnated with 5% and 7% LPF compared with those with 2% LPF and the control boards. This suggests that the LPF had significantly prevented the strand board from moisture uptake.

Dimensional stability

Thickness swelling and water absorption

After two hours of soaking, the TS of three-layered boards showed significantly lower TS, even at 2% LPF, compared with the five-layered boards (Figure 1). The five-layered board only exhibited significant reduction in the rate of swelling at 7% LPF. After 24 hours of water soaking, both the three- and five-layered control (0% LPF) boards absorbed water and swelled significantly more than LPF-treated boards (Table 2). Generally, there was no significant difference in TS between the three- and five-

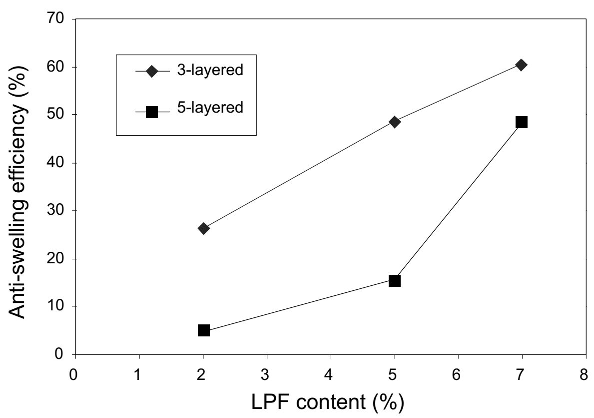

Figure 1 Relationship between LPF content and anti-swelling efficiency (ASE)

Table 1 Board density and moisture content of three- and five-layered strand boards after conditioning

Board property	LPF content (%)			
	0	2	5	7
	Three-layered strand board			
Board density (kg m^{-3})	719	734	747	762
Moisture content (%)	10.0	10.5	9.8	9.5
	Five-layered strand board			
Board density (kg m^{-3})	692	711	706	749
Moisture content (%)	10.2	9.6	9.5	9.4

Conditioned at 65% RH and 25 °C

Table 2 Thickness swelling and water absorption of three- and five-layered strand boards after cold water treatment

Panel structure	LPF content (%)	Thickness swelling (%)		Water absorption (%)	
		2 hrs	24 hrs	2 hrs	24 hrs
Three-layered	0	4.30	11.3	22.8	46.2
		(2.1)	(2.6)	(12.0)	(10.4)
	2	3.3	8.3	13.3	34.5
		(0.9)	(1.2)	(2.5)	(5.1)
	5	1.7	5.8	12.3	29.1
		(0.6)	(1.8)	(1.9)	(4.0)
	7	1.2	4.4	13.0	28.7
		(0.4)	(1.3)	(1.6)	(3.2)
Five-layered	0	4.3	10.6	22.6	49.2
		(0.4)	(0.8)	(4.2)	(8.34)
	2	3.9	10.1	17.3	40.1
		(0.5)	(0.7)	(3.6)	(7.43)
	5	3.8	9.0	20.3	42.6
		(0.3)	(1.1)	(7.0)	(11.49)
	7	3.2	5.5	19.4	33.7
		(0.3)	(0.6)	(4.3)	(4.98)

Values are average of six specimens and corrected to board density of 650 kg m^{-3}.
Values in parentheses are standard deviations.

layered boards, even though the latter experienced smaller degree of swelling (10.6 vs. 11.3%).

Increasing the amount of LPF significantly improved the stability of three-layered strand board. This relationship can be clearly seen when evaluating the effects of LPF content and anti-swelling efficiency (ASE) (Figure 1). Both three- and five-layered boards showed that ASE increased in an almost linear manner with LPF. The largest ASE value of 61% was attained by three-layered strand board that contained 7% LPF resin loading. The TS of this board was also the lowest (4.4%).

The incorporation of LPF resin reduced the extent of water absorption (WA) (Table 2). The increase in resin loading reduced overall WA after 24 hours of water soaking. The WA showed significant improvement especially between the control (untreated) and pretreated strand boards.

The results of overall TS and WA suggest that the strand board treated with PF resin significantly improved the dimensional stability of the panel. The scanning electron micrographs (SEM) across the strands in the strand board showed the effects of LPF impregnation on the wood cell structure. Figure 2 shows SEM of PF deposited and cured in a few vessels in all the four strand board samples. Relatively larger amount of PF was observed in the vessels of the panel treated with higher LPF resin content (Figure 2d). In general, the overall appearance of the cross-sectional surface of the untreated sample (Figure 2a) was smoother compared with treated samples (Figures 2b, c, d). These differences in texture can be attributed to the deposition of LPF in the cell wall of the wood, hence forming a brittle product that produced a rough surface after cutting.

Strength properties

Bending strength and stiffness

The modulus of rupture (MOR) (dry and wet) of LPF-treated boards increased significantly with an increase in LPF resin loading (Table 3). The extent of improvement, however, tends to diminish with the presence of fine particles on the surface of five-layered strand board. The three-layered strand board with 7% LPF exhibited the highest values of MOR (dry and wet) of 29 MPa and 19 MPa respectively.

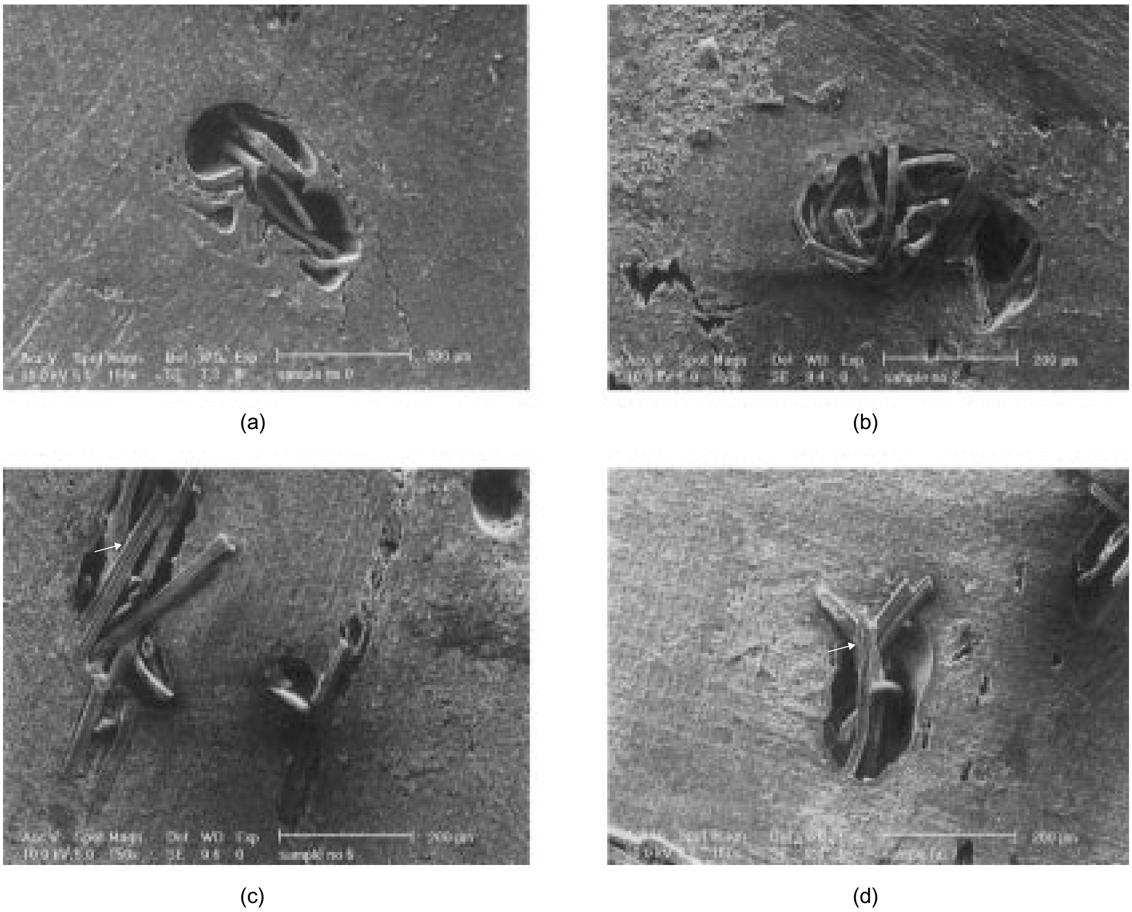

Figure 2 Scanning electron micrographs of cell wall structure in *A. mangium* (a) untreated strand board; (b) 2% LPF-treated strand board; (c) 5% LPF-treated strand board; (d) 7% LPF-treated strand board (Mag: × 150 / size 200 µm. Arrows indicate vessels filled with cured PF resin.

Table 3 Strength and bond quality of LPF-treated three- and five-layered strand boards

Panel structure	LPF content (%)	Modulus of rupture (MPa)		Modulus of elasticity (GPa)		Internal bond (MPa)
		Dry	Wet	Dry	Wet	
Three-layered	0	23.6	7.1	5.13	2.69	0.09
		(2.9)	(0.5)	(317)	(153)	(0.01)
	2	23.4	13.1	5.72	3.13	0.11
		(1.5)	(2.8)	(780)	(552)	(0.03)
	5	23.4	14.3	6.35	4.58	0.16
		(4.8)	(0.9)	(834)	(142)	(0.06)
	7	28.7	19.2	8.25	5.97	0.24
		(3.9)	(2.3)	(734)	(271)	(0.03)
Five-layered	0	16.3	7.8	4.04	1.95	0.08
		(1.1)	(1.5)	(606)	(397)	(0.02)
	2	16.7	8.4	4.15	2.14	0.10
		(2.0)	(0.2)	(331)	(236)	(0.01)
	5	23.8	12.6	4.16	2.13	0.19
		(2.8)	(0.4)	(492)	(492)	(0.02)
	7	24.9	12.6	4.44	2.58	0.21
		(1.5)	(0.7)	(505)	(98)	(0.02)

The modulus of elasticity (MOE) for dry and wet three-layered strand board increased significantly with increasing LPF loading level (Table 3). The highest MOE (8.3 GPa) was recorded on three-layered strand board treated with 7% LPF. All the five-layered strand boards had rather inferior properties compared with the three-layered boards.

The overall values of MOR and MOE of LPF-impregnated strand board were to be expected for a typical board having fine particles on its surfaces. Particularly the three-layered strand boards had values greater than those of control boards. Similar observation was also reported by other researchers (Kajita & Imamura 1991, Wang *et al.* 2000) where the incorporation of 5% phenolic resin in wood strands was found to improve the strength properties of the resulting boards by 10% and stiffness by 40%. When the LPF -impregnated strands mat was pressed under high temperature (175–180 °C), the effects of plastic deformation of strands and mobility of PF resin were elevated. The high temperature assists in distributing the resin evenly, especially for wood strands near the surface. Eventually, the top and bottom layers of strand board were densified to higher density with smoother surface as compared with the inner layer, making a stronger board. The MOR and MOE, however, reduced when fine particles were added onto the board surfaces. Wang and Chen (2001) also reported that arranging smaller particles on the board's surfaces will significantly reduce the strength of the board.

Wet strength retention

The wet strength retention of strand board was measured after hot and cold water treatments. These values were expressed as a percentage of their respective dry strength. The degrees of MOR and MOE retention increased with increasing resin loading for both three- and five-layered strand boards (Figure 3). The effect was greatest in a three-layered strand board having 7% LPF where 67% of MOR was retained. The five-layered strand board treated with 7% LPF retained as much as 58% of its MOR. The untreated boards (control) retained only 30% of MOR in three-layered boards and 48% of MOR in five-layered boards.

Internal bond strength

The IB of strand board ranged from 0.08 to 0.24 MPa (Table 3). The highest IB was recorded for three-layered strand board with 7% LPF which was 0.24 MPa. The five-layered strand board bonded with 7% LPF attained 0.21 MPa. All the produced strand boards had extremely low IB although their values increased with an increasing amount of LPF. This may be attributed to the insufficient hot pressing time (about 7.5 min) for the heat to travel from the surface to the core of the board, in particular for the LPF-treated ones that were relatively wetter compared with the control boards. The LPF is expected to have higher content of lower molecular weight components, hence requiring longer time to undergo cross-linking during hot pressing. Increasing the press time from 7.5 min to 10.5 and 11.5 min on the five-layered strand boards resulted in much improved IB. Additional curing of both the PF and the LPF resins in the wood cell wall apparently is responsible for this improvement.

CONCLUSIONS

The LPF impregnated three-layered strand board performed better than the five-layered board. Pre-treating the wood strands with LPF resin resulted in significant improvement in TS and WA after 2 and 24 hours cold water soaking. Impregnating the strands with 7% LPF prior to

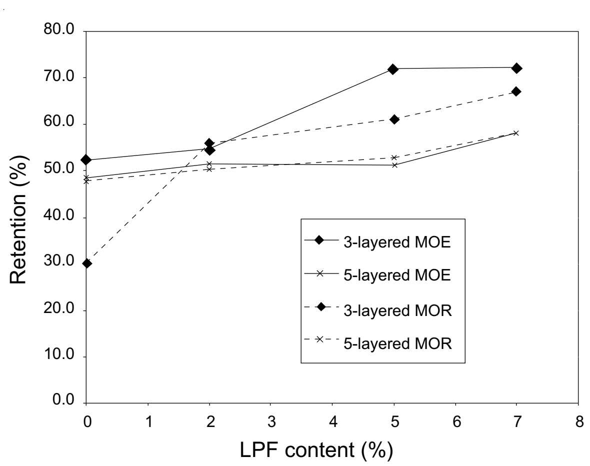

Figure 3 Effects of LPF content on the stiffness and strength retention of three- and five-layered strand boards after hot and cold water treatments

board formation resulted in the three-layered board having up to 61% ASE. Significantly high MOR and MOE values were recorded as higher amount of LPF was used. Highest MOR (29 MPa) and MOE (6.3 GPa) were exhibited by three-layered boards with 7% LPF impregnation. The panels were also more stable even after being subjected to hot and cold water treatments. The LPF-treated boards required longer time for curing. Acceptably high IB was achieved by increasing the hot pressing time to > 10.5 min at 175 °C.

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