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Research paper

Oriented Strand Board using Smaller Strand Size as a Core Layer

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Abstract

As a direct effect of its rapid growth, *Leucaena leucocephala* tree could be a leading raw material for bio-based composite panels. This fast growing tree and lesser used species in the wood industry can expand the choice of raw material for production of value added products. In this study, board properties of OSB using smaller strand size of *Leucaena leucocephala* as core layer, physical and mechanical properties were found to be affected significantly by board density and resin content except for MOR in minor axis. However, strand size did not affect physical and mechanical properties except for MOR in major axis. Effects of board density on the mechanical properties were found to affect significantly different. The board density showed a significant effect on thickness swelling with a positive correlation. There is no significant difference on bending properties, internal bond strength and thickness swelling between combination of strand size of S1+S3 and S2+S3. Effect of resin content on bending properties showed significant difference of MOR in major axis and MOE values in both major and minor axis. Generally all treatment of OBS passed the general requirement of general purpose OSB even when the resin is as low as 5%.

Keywords: *Strand, density, resin content, phenol formaldehyde, bonding*.

1. Introduction

The popular panel product of choice in Malaysia is plywood, in which it has contributed up to 20% of major timber and timber products for Malaysia export in 2016 [1]. The reduced supply of good quality and big diameter timber is a good reason to look for an alternative panel product which can supplement the plywood usage. Orientated strand boards (OSB) comprises of strands with larger length to width ratio normally aligned to efficiently obtain high strength. In Norths America it has replaced plywood in areas such as sheathing panels for wall, roof and floor application [2]. It utilizes smaller logs with lesser quality imposition than plywood. The smaller log, likely from faster growing species can elevate pressure of getting supply from current forest bank of Malaysia. Leuceana spp. is one of fast growth species that Typically OSB will be produced in as three layers with coarse strands as core and smaller strands as face and back.

2. Materials and Methods

In this study, *Leucaena leucocephala* wood was used as the raw material and phenol formaldehyde (PF) resin as a binder with 3 levels of resin content of 5%, 7% and 9% based on dry weight. The board dimension is 380 mm x 380 mm with a thickness of 12 mm. In general, the manufacturing process for OSB starts with debarked logs which are then sliced into thin wood elements. The strands are dried, blended with resin, and formed into thick, loosely consolidated mats that are pressed under heat and pressurised into boards. Flow process to manufactured oriented strand board is shown in Fig 1. The board utilized smaller strand size of S3 as core material in the manufacture of OSB using eight-year-old wood strands of *Leucaena leucocephala* wood.

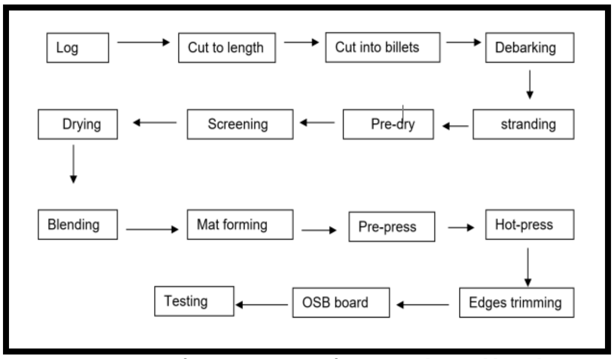

Fig 1: Manufacturing process for oriented strand board

Smaller strand size of S3 or fines is considered to be any wood particles that pass through a 6.3 mm screen and remain at 3.2 mm screen. They are an inherent by-product of the stranding process and used in the board as filler material. They contribute to the mass of the board but are assumed not to affect the final volume of the board. An optimal manufacturing would operate at a balance of wood strands and fines that meet the strength requirements and minimizes the raw material cost. In this study, strand size of S3 was located in the middle layer of the board while strand size of S1 (strand width 19 to 12.7mm) or S2 (strand width 12.7 to 6.3mm) were located at the face and back layers.

3. Results and Discussions

Table 1 exhibits the properties of OSB according to board density, strand size and resin content. In the manufacture of boards having target board density of 700 kgm^{-3}, boards from S1S3 with 9% resin content gave the best value of physical and mechanical properties (MOR major axis; 43.57 MPa, MOE major axis; 7377 MPa, MOR minor axis; 16.26 MPa and MOE minor axis; 1596 MPa, Internal Bond; 1.20 MPa and thickness swelling; 12.05%). However, boards made from S2S3, density of 700kgm^{-3} and 5% resin content found to possess the lowest values for mechanical properties in major and minor axis except for MOE in major axis.
The board also exhibited the highest percentage of thickness swelling with 20.43% but still meeting the minimum requirement of EN standard. The highest values of MOR in major axis were 2.4 times greater than the specification of the EN standard. Furthermore, the value of MOR in major axis was also perform 37.32% higher than MOR in minor axis. MOE values in major axis perform tremendously with 3 times greater than minimum requirement. The internal bond values of OSB board improved substantially by increasing resin content from 5 to 9 percent. Improvements ranged from 1.7 to 1.8 times greater than the internal bond of 5 percent resin content. Overall, those boards with 9% resin content had the best thickness swelling. Based on the findings of the study, even at the lowest resin content of 5%, physical and mechanical properties were found to comply with EN 300 standard for general purpose (type OSB/1).

Table 1: Properties of OSB

				Major Axis		Minor Axis			
Target Density (kgm^{-3})	**Strand Size**	**Resin (%)**	**Actual Density (kgm^{-3})**	**MOR (MPa)**	**MOE (MPa)**	**MOR (MPa)**	**MOE (MPa)**	**IB (MPa)**	**TS (%)**
700	S1S3	5	699	38.11	6455	15.94	1444	0.64	15.75
700	S1S3	7	695	40.70	6703	16.84	1485	0.79	14.11
700	S1S3	9	707	43.57	7377	16.26	1597	1.20	12.05
700	S2S3	5	697	36.00	6684	14.41	1444	0.57	20.43
700	S2S3	7	695	39.73	6929	14.29	1483	0.90	15.19
700	S2S3	9	703	41.05	7013	14.71	1569	0.98	12.30
800	S1S3	7	793	52.12	7324	18.22	1624	0.92	19.42
800	S1S3	9	797	56.24	8555	20.66	2024	2.06	12.93
800	S2S3	7	792	46.08	7663	18.67	1804	1.34	15.34
800	S2S3	9	799	51.03	7783	19.76	2003	1.92	15.07
	Min. req.			18 MPa	2500 MPa	9 MPa	1200 MPa	0.28 MPa	<25%
Type OSB/1: General purpose EN Standard				EN 310: 1993	EN 310: 1993	EN 310: 1993	EN 310: 1993	EN 319: 1993	EN 317: 1993

Note: MOR = Modulus of Rupture, MOE = Modulus of Elasticity, IB = Internal Bond, TS = Thickness Swelling

The boards with target board density of 800 kgm^{-3} with combination of strand size S1S3 at 9% resin content gave the highest values of MOR and MOE in major and minor axis. The MOR and MOE values in major axis reach 56.24 MPa and 8555 MPa, respectively. The highest value in minor axis was 20.66 MPa for MOR and 2023 MPa for MOE. The board also exhibited the highest internal bond values with 2.06 MPa and 7 times greater than the specification of the EN standard. The board also exhibited lower thickness swelling with 12.93%. However, boards made from target density of 800 kgm^{-3} with strand size of S1S3 and 7% resin content was found to possess the lowest values for mechanical properties in major and minor axis except for MOR in major axis. This board also exhibits the higher percentage of thickness swelling with 19.42% but still meeting the maximum requirement of 25% and below.
The observation from this study showed that boards at 7% resin content exhibit spring back phenomena where the boards experience increase in thickness more than 12 mm (Fig. 2). By reducing the board's density and increasing resin level, the 'springback' effect was decreased. Therefore, based on performance at 7% resin content, the manufacture of boards with 5 percent resin content was not conducted. No data was recorded from the treatment of S1S3 and S2S3 at board density of 800kgm^{-3} with 5% resin content because the board specimens blow in the core layer. Generally, boards with strand size of S1S3 perform better than S2S3 and all boards meet the minimum requirement of EN 300.

a) S1S3 b) S2S3

Fig. 2: Spring Back Phenomena

3.1 Statistical Significance

The analysis of variance (ANOVA) and correlation analyses are presented for discussion. The ANOVA of the effect of board density, strand size and resin content and their interactions on the OSB properties are shown in Table 2.

Table 2: Summary of the ANOVA on the Properties of S1S3 and S2S3 Board

	Major Axis		Minor Axis			
SOV	MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%)
D	51.90**	40.57**	22.97**	21.03**	115.48**	6.76*
S	5.66*	0.0ns	1.91ns	0.08ns	1.58ns	0.69ns
RC	5.80*	17.51**	0.84ns	6.19*	74.26**	13.25**

Note: SOV= Source of variance, Df = Degree of freedom, ns= not significant at p>0.05, * significant at p<0.05, **highly significant at p<0.01

Statistical analysis indicated that density affected mechanical properties and thickness swelling. However, strand size did not affect mechanical properties and thickness swelling except for MOR in major axis. All the mechanical properties and thickness swelling were found to be affected significantly by resin content except for MOR in minor axis. Interaction between board density and strand size shows no significant difference except for internal bond. Similar trend was also observed for interaction between board density and resin content. Nevertheless, the interaction between strand size and resin showed no significant difference except for MOE in major axis and internal bond strength. No significant effect was observed in interaction of all main factors.

3.2. Effects of Board Density

The effects of board density on physical and mechanical properties are given in Table 3. The mechanical properties showed higher value with increase in board density. The t-test comparison shows that the mechanical properties are significantly different at $p<0.05$. The value of MOR and MOE in major and minor axis of each board increased almost linearly with increasing board density. The MOR in the major axis was around 2.6 times greater than that in the minor axis. A similar trend in effects of density was observed in MOE. According to [3], in general the values of MOR and MOE in parallel direction are about 40% to 50% higher than the values determined in perpendicular direction. Correlation analysis (Table 4) indicated that the properties of MOR major axis, MOE major axis, MOR minor axis, MOE minor axis and internal bond increased with increased board density (r = 0.68**, 0.59**, 0.56**, 0.50** and 0.61**, respectively). [4] reported that board density was one of the most important factors that affected mechanical properties of particleboard. Board density is the main factor for board structure to bear load in the wood composites, so the increase of density means to increase the resistance of materials to the outside forces, and achieve good contacts of composite units for improving bonding strength. [5] investigated three different board densities (0.53, 0.66 and 0.78 gcm^{-3}) and found that mechanical properties increased as panel specific gravity increased for Douglas-fir flake boards.

Table 3: Effects of Board Density on Physical and Mechanical Properties

	Major Axis		Minor Axis			
Target Density (kgm^{-3})	MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%)
700	41.17b	6964b	15.49b	1535b	0.97b	13.52b
800	51.54a	7857a	19.22a	1844a	1.60a	15.69a

The internal bond also exhibits almost a similar trend to bending properties with a significant effect (Table 3). The correlation analysis (Table 4) further revealed a positive correlation between board density and internal bond strength (r = 0.61**) existed. Since smaller strand size (S3) is in the core layer it would be easier to increase the core density which leads to more intimate contact between strands and thus promoting better internal bonding. Higher amount of materials used in board density of 800 kgm^{-3} had contributed to stiffer board. According to [6], board density is one of the variables that have been examined that affect the internal bond of strand composite panels.
Table 3 shows there is significant difference in thickness swelling of the boards. Correlation analysis (Table 4) for thickness swelling shows a positive correlation with board density (r = 0.30*). A possible explanation for this behaviour relates to the higher density zone and higher fine particles in the core rebound to swell more when immersion in water. According to [7] higher density boards possessed more compression set than lower density ones when both were made with the same wood furnish, but expend more after immersion in water. [8] in their study found a good linear correlation between density and thickness swelling values. [9] reported that thickness swelling of OSB not only creates aesthetic problems in some applications, but is also associated with a loss in strength and stiffness of the material. However, board dimensional stability could be improved by decreasing board density [10].

Table 4: Correlation Coefficients of the Effect of Strand Size, Resin Content and Density on Board Properties for S1S3 and S2S3

	Major Axis		Minor Axis			
Variable	MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%)
Density	0.68**	0.59**	0.56**	0.50**	0.61**	0.30*
Strand Size	-0.18ns	-0.04ns	-0.18ns	0.06ns	-0.01ns	-0.02ns
Resin	0.27*	0.40**	0.09ns	0.29*	0.52**	-0.40**

Note: ns = no significant correlation *Correlation is significant at the 0.05 level,**Correlation is significant at the 0.01 level.

3.3. Effects of Strands

Table 5 shows the effects of strand size on physical and bending properties. There is no significant difference on bending properties between combination of strand size of S1S3 and S2S3. [11] found that for flakes of 5.0 and 7.5 cm long, length had no significant effect on MOR and MOE. This is due to the fact that smaller strand size makes denser structures between strands in core portion and bigger strand size of S1 and S2 react as stress supporter at face and back portion of the board. The distribution of large wood strands might cause the lower value of bending properties. [12] reported that large strands which should enhance on bending strength may be heavily disoriented whereas smaller strands which have less influence on the bending strength might be well oriented Boards with S1S3 strands experienced higher spring back because of more space or void in the core layer and at the adjacent layers of face and back (Fig. 3). However, boards with S2S3 strands experienced less spring back because smaller strand size of S2 contributed to create less void between S2 strands and S3.

Table 5: Effects of Strand Size on Physical and Mechanical Properties

	Major Axis		Minor Axis			
Strand Size	MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%)
S1S3	47.40a	7418a	18.01a	1678a	1.28a	14.63a
S2S3	44.59a	7351a	16.84a	1712a	1.27a	14.52a

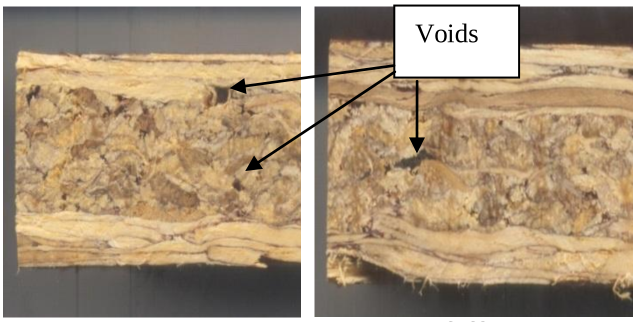

Fig. 3: Voids within the Board

According to [13] presence and distribution of macro-voids are generally governed by the bigger and longer strand, which could be filled by smaller strand size to reduce the gap. Generally, increased proportions of smaller strands had negative effects on the board mechanical properties. The correlation analysis (Table 4) further revealed that the mechanical properties showed insignificant (r = -0.18ns, -0.04ns, -0.18ns and 0.06ns) correlation with of strand size. [14] reported that the MOR and MOE of the boards were not affected greatly with increase in strand size.
Internal bond strength is one of the important mechanical properties. In the internal bond test on boards made from strand size of S1S3 and S2S3, most failure occurred in the wood portion and not at the adhesive or glue line (Fig. 4). The statistical analysis indicated that internal bond strength of boards was not affected by the strand size used in the study (Table 4). The correlation analysis (Table 4) further revealed that the internal bond strength showed insignificant (r = -0.01ns) correlation with decreased of strand size. According to [15] internal bond strength showed no further increased for boards with 30% fines content, and even decreased as fines is further increased to 45% probably due to poor bonding resulting less resin coverage on surfaces of wood fines. [16] observed that during the hand-forming process, wood elements are deposited randomly throughout the horizontal plane in a more or less layer-by-layer fashion, and voids can result between any adjacent elements in any layer. As flake size increases, the number of these voids decreases in a unit area within one layer, while the size of voids increases.

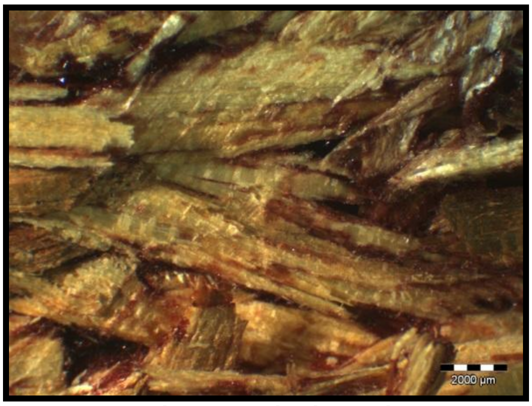

Fig. 4: Failure Occurred in the Wood Portion

After 24-hour soaking, the strand size showed no significant effect on thickness swelling values at 95% significant level (Table 4). The results show that combination of strand size of S2S3 boards had a competitive performance as compared to combination of strand size of S1S3. The statistical analysis indicated bigger strand size of S1 and S2 in the face and back layers had an excellent role to resist the board to swell more with no significant different between boards made from S1S3 and S2S3 strands. This treatment strategy showed that by using strand size of S1, S2 and S3 can maximise recovery without jeopardising board properties. The correlation analysis (Table 4) further revealed that the thickness swelling values showed insignificant (r = -0.02ns) correlation with strand size. [17] reported that thickness swelling of smaller strand size at the core center of the OSB was higher than that in the surface region.

3.4. Effects of Resin Content

Table 6 the effect of resin content on bending properties. The statistical analysis shows significant difference of MOR in major axis and MOE values in both major and minor axis. However, MOR shows insignificant difference in minor axis with increasing resin content.

Table 6: Effects of Resin Content on Physical and Mechanical Properties

	Major Axis		Minor Axis			
Resin (%)	MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%)
7	44.09b	7090b	17.16a	1608b	0.99b	15.97a
9	48.14a	7693a	17.72aa	1789a	1.52a	13.09b

The correlation analysis (Table 4) further revealed that the bending properties of MOR in major axis, MOE in major axis, MOR in minor axis and MOE in minor axis shows a positive correlation with increased of resin content (r = 0.27*, r = 0.40**, r = 0.09ns and r = 0.29*, respectively). Lower performance by 7% resin content is due to insufficient resin available to bond smaller strand size especially for S2 and S3. Higher board density and the presence of smaller strand size had created less bonding contact because smaller strand size absorb more resin and created uneven resin distribution among smaller strands during blending process. Therefore, smaller strand size or fines led to insufficient resin coverage on the surface and resulted in poor strength performance ([18], [19], [20], [21]). Nevertheless, the boards with 7% resin content are comparable to boards with 9% resin content for rupture property. Therefore, it may be possible to manufacture the boards at lower resin level. According to [22] high-cost resin adhesive must be used at reasonable application rates catering for both the excellent properties of the product and the economic feasibility. When considering lower application rates, consideration of superior performance and quality of the composite must be maintained.

Table 6 shows a significant difference with increasing the resin content on internal bond strength. The correlation analysis (Table 4) further revealed that a positive correlation between resin content and internal bond strength (r = 0.52**) showing that increasing resin content had improved bonding performance. From the observation, high amount of resin content is required for good a bonding especially for small strand geometry (S3; core layer). According to [23] using high levels of wood fines in the core layer can lead to decreased internal bond strength when insufficient resin content is used. A study by [24], reported that much less resin was required for finer particles in high-density surface zones than for lower density core areas with coarser particles. This finding shows the need for good bond formation which could be attained with good board forming parameters.

Boards made with 9% resin content show significantly lower thickness swelling after 24 hours of immersion in water (Table 5). By increasing resin content, the thickness swelling decreased. The dimensional stability of the boards was shown to be greatly improved (19%) when resin content was increased to 9%. The correlation analysis (Table 4) further revealed that there is negative correlation between resin content and thickness swelling (r = -0.40**). Basically the board experiences dimensionally instability when immersed in water and with the increase in resin content improves the board stability against water exposure. [25] reported that normally, board decreases in thickness-swell with the increase of resin content.

4. Conclusion

Generally all treatment of OBS passed the general requirement of general purpose OSB even when the resin is as low as 5%. Use of PF gave good dimensional stability to the boards. Economically OSB should be made with lowest possible density and lowest resin content as permissible to the product requirement. Smaller size stands seemed to be acceptable for in OSB manufacture thus can reduce waste of raw material. Formation of boards and lower springback will aid formation of good economical boards.

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