International Journal of Engineering & Technology, 7 (4.18) (2018) 200-203

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Improvement of Flexural Properties and Dimensional Stability of Rice Husk Particleboard Using Wood Strand from *Azadirachta excelsa* in Face Layer

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Abstract

Improvement of flexural properties and dimensional stability of rice husk particleboard is targeted in this study. Hybrid boards utilizing *Azadirachta excelsea*strands at surface and rice husk as core was manufactured and tested. Rice husk particleboardscontaining five percentage ratio of *A.excelsea* (0, 10, 20, 30 and 40%) were tested.Additional work was done with 40% *A.excelsea* content with random and aligned arrangement to observe effect of strands layout. The results showed significant ($p \leq 0.05$) improvement in flexural strength (modulus of rupture, MOR and modulus of elasticity, MOE) as the face layer percentage increases. The dimensional stability (water absorption and thickness swelling) with 40% *A.excelsea* content showed the best performance. Arrangement of strand showed alignment improved MOE but internal bond, MOR and physical properties were not significantly affected. Overall there is potential to improve the flexural properties and dimensional stability with variation of strands percentages at face layer.

Keywords: *Azadirachta excelsea; flexural strength; dimensional stability; particleboard;strands ratios*

1. Introduction

Wood-based industry in Malaysia contributes RM21 billion in export revenue in 2017. Latest fig. for January to April showed export earnings of RM7.1billion in which more than 60% comes from the furniture and panel-based products [11]. As the third largest contributor of Malaysia export revenues, it is important for the industry to have sustainable source of raw material for production.

Currently the industry is dependent on mix-tropical species which originated from the natural forest. The mix-tropical species is normally used in combination with rubberwood. Planted rubberwood, can be used in the wood-based products after it reached its uneconomical latex production age. This normally takes 15 to 20 years cycle. At this point rubberwood is highly demanded by solid wood-based product user and the composites manufacturer. However, replanted rubberwood hectare has been declining as it is being replaced by oil palm plantation. In the future, the volume from rubberwood would not be able to cater the industrial needs.

As part of Malaysian Government action for replacement or supplement of raw material for the wood-based industry, *Azadirachta excelsa* has been identified as one of the eight named species by Malaysian Timber Industrial Board (MTIB) to be planted in a managed forest environment. *Azadirachta Excelsa* (scientific name) orlocally known as Sentang is of genera *Azadirachta* and belongs to the Meliaceae family. In Peninsular Malaysia it is known as "Sentang elephant" or "Sentang onions", while in Sabah it is called "Ranggau" or "Limpaga" [8]. *Azadirachta excelsa* had been planted at Sabah, Malaysia and has average green density of 0.74 g/cm3 [20]. The target was to develop viable forest plantation species. In the process of planting, *A. excelsa* which has been chosen for its straight bole forming species was found to be lacking in its characteristic. Subsequently, another potential usage for the tree was to form strands and particles which could be utilized in the production of oriented strands board and particleboard respectively.

Alternatively, agricultural residue material such as bagasse, cereal straw, corn stalk, cotton stalks, kenaf, rice husk, sunflower hulls and sunflower stalk technically can be used to manufacture composite panels [21]. According to [7] rice husk has the same basic component as wood but in different proportions. Malaysian rice cultivation (developed and under development) cover a region of around 600, 000 hectare and 65% of the coverage is situated in Peninsular Malaysia [6]. With 2 million tons metric paddy per year produced [6], this amounts to 270, 000 metric tons paddy husks obtained in Peninsular Malaysia annually. Commercially, rice husk is mixed with broken rice and are used as animal feed. Some are used as fuel during rice processing [2]. A large portion was burned as standard methods to reduce storage cost, which contribute to air pollution. As an alternative, rice husk may be utilized as fibrous material in making engineered wood such as particleboard which can be used by the furniture industry. It has a few advantages such as environmentally friendly nature, low cost, availability and sustainability. According to Padiberas Nasional Berhad(BERNAS) [5] calendar, harvesting of paddy in Peninsular Malaysia was at different cycle for every different state in one calendar year.

Various works in utilization of rice husk in board normally comes to the same issue of flexural and dimensional stability. For [19] board produced at densities up to 800kg/m^3 still give high swell-

ing properties, thus limiting the board for indoor use. Similarly [7] attempted a more bio-friendly approached using soybean protein concentrate enable them to acceptable flexural particleboards properties but failed to achieve recommended thickness swelling value. For [10], substitution of the rice husk particles by the wood strands up to 40% in the face of hybrid rice husk particleboards shows success in substantially affecting the flexural properties. Team of [8] continued with resin content variation for rice husk and concluded that particleboards have a better dimensional stability than panels obtained from other agro-industrial wastes.
Product such as oriented strand board is usually used as structural panel. It has high flexural strength and good dimensional stability. A combination of rice husk particleboard at core with strands at surface layer may help to improve rice husk particleboard dimensional stability. With improvement of rice husk particleboard properties, it is possible to fill the need of the wood panel-based industry.

2. Materials and methods

For enhancement of rice husk particleboard flexural strength, three layers board with surface strand *A. excelsa* (Sentang) and core from rice husk particle was designed. The rice husk was taken from local rice factory at Jitra Kedah and screened to separate the dust from the particle. Sentang was harvested from Universiti Teknologi MARA (UiTM), Pahang Education Forest and strands of *A. excelsa* were prepared via flaking. Strand dimension were: length 90 to 100 mm, width 15 to 20 mm and thickness 0.8 mm. Commercially available phenol formaldehyde (PF) resin was used at dosage of 8% core and 11% surface.

Both particles were dried at 75^0C till moisture content of below 5% and separately blended with pre-calculated resin content. Board dimension used was 350 x 350 x 12 mm with target density of 600kg/m^3. The density was selected taking into consideration of potential spring-back from the rice husk core.The mats were formed with wood strands, rice husk and wood strands layer. The layered material was then cold pressed followed by hot press at 165^{o}C. Pressure cycle used was 1800 psi (3 min):1200 psi (2min): 800 psi (2 min). Complete boards were subjected to 24 h conditioning at 20^{o}C and 65 % relative humidity (RH) before trimming and sizing. The board was cut to size based on Malaysian standard (MS) for flexural properties [14], internal bond (IB) [15] and physical properties test (water absorption (WA), and thickness swelling (TS) [13].

For this study, ratio of wood strands of 0, 10, 20, 30 and 40% to rice husk were used. For each treatment, particleboard was prepared in triplicate with random strand arrangement. For 40% ratio, both random strand arrangement and aligned strands arrangement were prepared.

3. Result and discussion

The densities of boards produced increased following the increase of wood strand percentage. Results showed values of: 0% (604 kg/m^3), 10% (609 kg/m^3), 20% (612 kg/m^3), 30% (618 kg/m^3) and 40% (624 kg/m^3). This relates well to the density of rice being between 90-150 kg/m^3 and densities for the *A. excelsa* wood ranging from 560-770 kg/m^3 [20]. The increase in strands ratio in the rice husk particleboards resulted in increased board's compactness.

3.1. Effect of wood strand addition

Compilation of the mechanical and physical properties of particleboards rice husk and wood strand are given in Table 1. The composite with 40% wood strand had the highest value for Modulus of Rupture (MOR) at 19.68 MPa and Modulus of Elasticity (MOE) at 6140 MPa. The trend of MOR and MOE is further given in Fig. 1 with significant differences between results are designated using characters a, b and c subsets following results from Duncan Multiple Regression Test (DMRT) analysis.

Table 1: Flexural strength and physical properties of rice husk board layered with wood strands

Wood ratio (%)	MOR (MPa)	MOE (MPa)	WA 24 hr (%)	TS 24hr (%)
0	4.58c (1.25)	2252c (399.2)	109.6a (12.2)	24.80a (4.66)
10	5.75c (2.32)	2795c (1003.2)	108.2ab (18.1)	23.56ab (3.33)
20	11.99b (3.81)	4100b (617.3)	93.5c (16.3)	21.85ab (3.97)
30	12.02b (2.67)	4216b (674.3)	94.6bc (15.4)	20.99b (3.72)
40	19.68a (5.98)	6140a (991.4)	90.8c (15.5)	21.57ab (4.66)
MS1036, PF2 requirements	14	2000	-	15

Note: Value in parenthesis ( ) denotes standard deviation. Letters a, b, c denotes different subsets. Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Water Absorption (WA), Thickness Swelling (TS), PF2 furniture grade particleboard used in humid conditions

Generally, increasing the amount of *A. excelsa* strands ratio on the face layer from 0% to 40% increased the MOR and MOE result. For MOE results, the wood ratios of 0% and 10%, 20% and 30% and 40% forms 3 separate subsets, indicating significant differences. This is confirmed by the analysis of variance shown in Table 2. The range of value 2252 to 6140 MPa showed that the minimum value for MOE at the 0% strands ratio is enough to satisfy MOE requirement of MS of PF2. Work done by [1], managed to observe MOR 6.86 MPa and MOE 1393 MPa for 650 kg/m^3 board with 12% urea formaldehyde resin level for pure rice husk board. This is lower to the finding in this study for 0% strands for MOE but higher than the corresponding MOR.

Table 2: Analysis of Variance on the Mechanical and Physical Properties Composite Board

Sources	Df	MOR	MOE	TS 24 hr	WA 24 hr
Wood strands ratio	4	33.96*	45.71*	5.78*	2.67*

Note: Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Water Absorption (WA), Thickness Swelling (TS)
* F-value are significant at $p < 0.05$ level

Based on Fig. 1, the increased of wood strands ratio increased the MOR strength. MOR results showed the same trend in significant difference to MOE. The MOR value steady increment only emphasized the need of a surface layer that is strong. While the minimum value for MOR was seen at 0% wood ratio (4.58 MPa) the maximum value was located at 40% wood ratio with value 19.68 MPa. Only 40% wood ratio on the particleboard surface managed to satisfy the MS requirement of PF2.

The added rice husk particleboards by wood strand up to 40% appeared to be successful, as it totally affected the flexural properties of the particleboards. The increasing number of wood ratio had improved the MOR and MOE results. According to [2], the result of bending test increases respectively when boards from agricultural fiber are added with wood fiber. Higher face layer density also contributes to the bending strength of board [3].

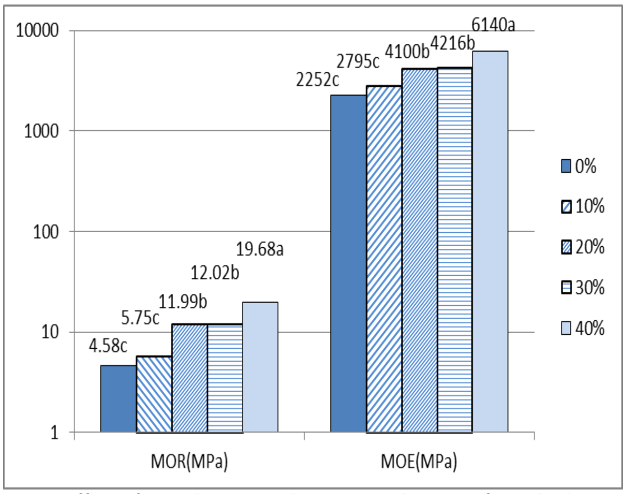

Fig. 1: Effect of strandsratio on the MOR and MOE of rice husk particleboard

The physical properties of composite boards using rice husk and wood strand are also shown in Table 1. It was found that WA and TS were at highest percentage value for 0% of wood ratio, which was 109.6% and 24.8% respectively. Fig. 2 showed graphically the effect of wood strands ratio on the TS and WA properties. At 24 hours TS results, significant difference was shown at 0% and 30% wood ratio. The maximum value for TS at 24 hours for 0% wood ratio was found to be 24.8%, which reflects poor TS properties, compared to other boards. The minimum value for TS at 24 hours was represented by 40% wood ratio with the value of 20.9% indicating better TS properties compared to others. The surface of 40% wood ratio gave a more compact structure with less porosity. The densities for the increasing strands content of board as indicated earlier contributes to the lower TS reading.

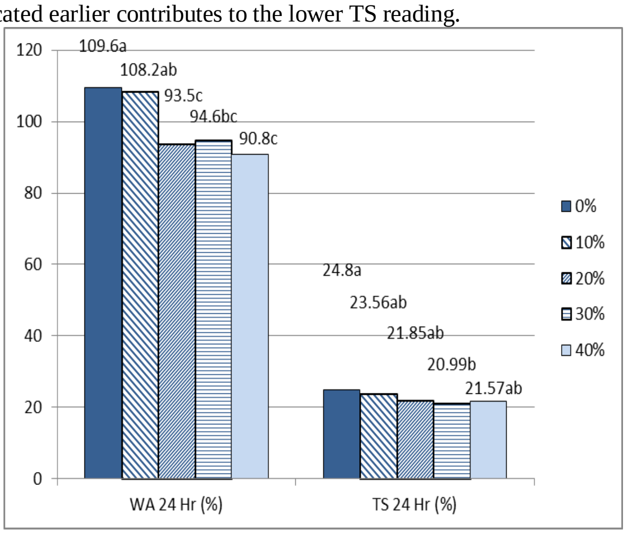

Fig. 2: Effect of strands ratio on the TS and WA of rice husk particleboard

Fig. 2 trend indicated reducing WA as the wood ratio increases from 0% to 40%. Boards from 40% wood ratio had better result in resistance to WA compared to other boards. A slight reverse trend is seen between the 20% and 30% wood ratios. These unexpected results can also be found in previous research by [12]. The DMRT of WA had no significant difference for 0% wood ratio and 20% wood ratio and for 10%, 20% and 30% wood ratio. According to [4] dimensional stability of the rice husk particleboard improved respectively by addition of wood particle. Rice husk particleboard without wood strands has lower dimensional stability because the bonding performance between the rice husk particles was poor. According to [17] the rice husk particleboards lower dimensional stability is owed to the amount of silica content on the rice husk surface. This creates a hydrophobic surface which interferes with the adhesive and substrate interphase thus prevented strong bond between particle and binding agent. The relationship between wood ratios which affected dimensional stability of rice husk particleboards was seen by work of [9].

3.2. Effect of wood strand arrangement

The aligned *A. excelsa* strands arrangement was possible using mold with parallel compartment as opposed to random boards spreading of strands for the non-aligned strand surface. Table 3 demonstrates the mechanical strength and physical properties for the two said arrangements. Particleboard using 40% strands was chosen following finding in earlier phase of the study, where the PF2 requirement has been met by this combination. Boards with the aligned wood arrangement possessed better mechanical propertiesthan boards containing random wood strand arrangement.

Table 3: Mechanical and physical properties of rice husk board with random and aligned wood strand arrangement at surface

Wood ratio (%)	MOR (MPa)	MOE (MPa)	IB (MPa)	WA 24 hr (%)	TS 24hr (%)
Random	19.68a (5.98)	6140b (991.4)	0.43a (0.31)	90.87a (15.51)	21.57a (4.66)
Aligned	20.16a (4.38)	8514a (886)	0.44a (0.22)	91.91a (14.14)	21.46a (5.00)

Note: Value in parenthesis ( ) denotes standard deviation. Letters a, b, c denotes different subsets. Modulus of Rupture (MOR), Modulus of Elasticity (MOE), internal Bond (IB), Water Absorption (WA), Thickness Swelling (TS)

Based on Table 3 and Fig. 3, the arrangement of wood strand showed significant difference in MOE result. The difference between aligned and random strands arrangement for MOE was 2374 MPa an improvement of 38%. According to [12] mechanical properties of OSB improved when the direction of the wood strands is parallel. This is linked to the make-up of the strands having higher aspect ratio. The parallel arrangement will allow better contact and tangling of the strands used and this contributes to the increase in flexibility of the board. Strands formation also mimics the formation of veneers, which promotes high contact area resulting in good intimation contact point. This action in theory gave higher effective contact between binder and substrate, thus giving good MOE strength.

The MOR result however has no significant difference as the amounts of strands were both at 40% ratio. Arrangement of wood strands did not seem contribute to MOR improvement. The MOR of a board is very much dependent on the thickness and density at the surface layer. Compact surface formation with high density tends to give higher MOR. In the case of arrangement comparison, both styles still contain similar amount of material which would give close value of thickness and surface density. A slightly higher, yet non-significant MOR difference is expected as there is a possibility of better packing for the aligned strands. Thus, the random arrangement test samples showed a larger variation in strength (13.7 to 25.7 MPa) compared to the aligned strands (15.8 to 24.5 MPa). The aligned strands displayed a more uniform MOR reading.

Properties of internal bonding for composite boards have low results, which is 0.43 MPa for aligned wood strands and 0.44 MPa for random arrangement wood strands.This is expected as IB measures the core strength which remains constant and is less reliant on the surface strands orientation.As also found by [12], the internal bonding properties were not affected by arrangement of wood strand. According to [4], rice husk that was used as material at the core had low bonding ability with any adhesive caused by content of silica on the rise husk surface. Mechanical properties t-test for arrangement showed significant difference for MOE (0.000*) but no difference for MOR (0.970) and IB (0.900) at $p < 0.05$ level.

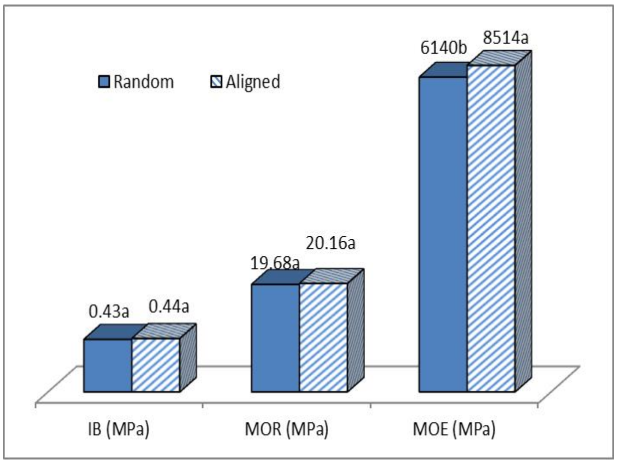

Fig. 3: Effect of *A. excelsa* strands arrangement on the mechanical properties of rice husk particleboard

Fig. 4 showed the dimensional stability properties of boards, TS and WA test results. Particleboard test samples were immersed in water for 24 hr. The WA at 24 hr for aligned wood strands was marginally higher than random wood strands. The higher value result reflectspoorer WA properties. Thickness and swelling at 24 hr showed random wood strands arrangement has better result than aligned wood strands. Possibility of resin pre-curing in the aligned board core has to be considered as the assembly time in laboratory scale from board formation till hot-press is longer.According to [12], arrangement of wood strands did not affect thickness swelling. The t-test analysis of the wood strands arrangement on the board's properties gave none significant effects for WA and TS of 24 hr at $p < 0.05$ level.

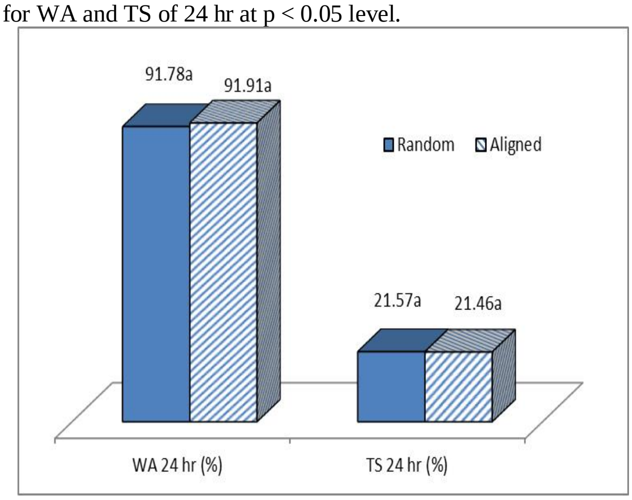

Fig. 4: Dimensional stability properties of rice husk particleboard for *A. excelsa* strands arrangement

4. Conclusion

The flexural properties of the boards were significantly improved by increasing the ratio *A. excelsa*strands. Having arrangement in parallel direction as opposed to random for *A. excelsa* strands also gave positively improved flexural properties. When the content of wood stands ratio increased from 0% to 40%, the improvement of resistance to TS and WA occurred. From the study, it is evidence that with increasing ratio of *A. excelsa*strands in face layers of rice husk particleboards, the flexural properties and dimensional stability of rice husk particleboards improved.For IB and physical properties, strands arrangement did not gave any significant contribution for enhancement.

The findings from this study suggest that the MOR of board with 40% wood strands satisfied the requirement specified by MS 1036:2006.Meanwhile, all boards with wood strands satisfy the requirement of MOE. Lastly, the TS of all boards did not satisfy the requirement as the values obtained exceeded 15%.

Acknowledgement

The authors would like to thank Malayan Adhesives and Chemicals (MAC) Sdn. Bhd. for supplying resin used in this research.

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