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THE EFFECTS OF LIGHT HARDWOOD VENEERS AND PRESS TEMPERATURE ON OIL PALM TRUNK SANDWICH BOARD MECHANICAL AND PHYSICAL PROPERTIES

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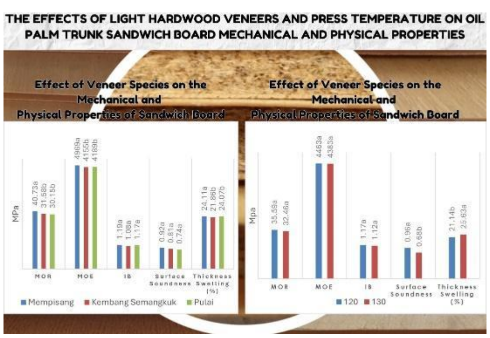
Graphical abstract



Abstract

The employment of wood as a raw resource linked with wood industry sectors is rising with population growth. Nevertheless, wood availability is declining. Producing sandwich boards (SB) with biomass resources could solve the issue. Oil palm trunks (OPT) can be transformed into high-value products and are readily available by replanting. In the current study, SB is modified by employing OPT as the core material and veneers as the face and back of OPT particle board and light hardwood veneers (LHW), including Kembang Semangkuk, Mempisang, and Pulai. The SB manufactured in this study was laminated with various veneers. The present study also utilized phenol formaldehyde resin at a 300 g m^{-2} spreading rate, while the sheet was pressed at 120°C and 130°C for 150 s and 180 s under 150 psi. The physical and mechanical properties of the resultant SB were evaluated according to the Japanese Industrial Standards (JIS) A 5908 (2003) standard. Surface soundness assessment was performed per the EN 311 (2002) requirements. The results indicated that the different veneer species significantly affected the SB rupture modulus, elasticity modulus, and surface soundness (SS) parameters. The different press temperatures employed also influenced the thickness swelling (TS) and specific strength of the board. The boards exposed to 120°C met all JIS standards, except for the TS parameters. Furthermore, the SB incorporated with Mempisang as the surface material demonstrated considerable surface soundness.

Keywords: Kembang semangkuk. light hardwood veneers, mempisang, pulai, sandwich board (SB)

Abstrak

Penggunaan kayu sebagai sumber mentah yang dikaitkan dengan sektor industri kayu semakin meningkat dengan pertumbuhan penduduk. Namun begitu, ketersediaan kayu semakin berkurangan. Menghasilkan papan sandwic (SB) dengan sumber biojisim boleh menyelesaikan isu ini. Batang kelapa sawit (OPT) boleh diubah menjadi produk bernilai tinggi dan mudah didapati dengan menanam semula. Dalam kajian semasa, SB diubahsuai dengan menggunakan OPT sebagai bahan teras dan venir sebagai muka dan belakang papan partikel OPT dan venir kayu keras ringan (LHW), termasuk Kembang Semangkuk, Mempisang, dan Pulai. SB yang dihasilkan dalam kajian ini telah dilaminasi dengan pelbagai venir. Kajian ini juga menggunakan resin fenol formaldehid pada kadar penyebaran 300 g m^{-2}, manakala lembaran ditekan pada 120°C dan 130°C selama 150s dan 180s di bawah 150 psi. Sifat fizikal dan mekanikal SB yang terhasil telah dinilai mengikut piawaian Piawaian Perindustrian Jepun (JIS) A 5908 (2003). Penilaian kekukuhan permukaan telah dilakukan mengikut keperluan EN 311 (2002). Keputusan menunjukkan bahawa spesies venir yang berbeza memberi kesan ketara kepada modulus pecah SB, modulus keanjalan dan parameter kekukuhan permukaan (SS). Suhu tekanan yang berbeza digunakan juga mempengaruhi pembengkakan ketebalan (TS) dan kekuatan khusus papan. Papan yang terdedah kepada 120°C memenuhi semua piawaian JIS, kecuali parameter TS. Tambahan pula, SB yang digabungkan dengan Mempisang sebagai bahan permukaan menunjukkan kekukuhan permukaan yang ketara.

Kata kunci: Kembang semangkuk, mempisang, papan sandwic, pulai, venir kayu keras ringan

1.0 INTRODUCTION

The demand for wood as a raw material for the timber industry is increasing. Nevertheless, wood from natural forests is decreasing and is affecting industry nationwide. Rising timber prices and natural resources shortages in the wood-based industry have resulted in studies on agriculture residues as novel and sustainable raw materials for producing environmentally friendly products. Biomass might offer alternative raw materials that are sustainable with performance potential [1].

Agricultural residue could be the new sources of material for the wood-based industry, including oil palm lumber, wood composites, veneers, plywood, laminated veneer lumber, pulp, and paper [2]. Wood composites could be employed as the primary raw material in furniture manufacturing. Furthermore, composites are suitable for generating novel, high-value products that are safe, cost-effective, and sustainable [3].

Agricultural residues from oil palm by-products, such as oil palm trunks (OPT), empty fruit bunches (EFB), and oil palm fronds (OPF), are abundant in the oil palm industry. [4] noted that OPT is a non-timber material containing lignocellulose and its biomass content is suitable as substitute wood, providing an alternative material to overcome the decline in timber from natural forests. Several reports on oil palm biomass utilization in manufacturing wood-based panels are available, including the manufacture of medium density fiberboard (MDF) from oil palm fibers [5], particleboards from EFB [1], cement boards from EFB [6], fiberboards from oil palm biomass [7], oriented strand board from oil palm biomass [8], sandwich particleboard from *belangke* bamboo, *tali* bamboo, sugar palm fibers, cornstalk, and sugarcane bagasse [9], and plywood from oil palm biomass [10].

OPT is considered an excellent oil palm residue due to its superior properties comparable to wood [11]. Nonetheless, OPT is commonly discarded or burned, leading to environmental concerns and resource waste [12]. As indicated by [13], OPT has a low density, high moisture content, and subpar mechanical attributes, limiting its direct employment as structural materials. Nevertheless, OPT can be manufactured into particleboards, an engineered product of resin-bonded wood particles. Manufacturing particleboards with OPT could improve the value of OPT and reduce wood dependence [14].

Based on their density and natural resistance to decay, commercial timbers are categorized into four classes: heavy, medium, light (angiosperm trees), and softwood (gymnosperm trees). Heavy hardwoods (HHW) are timbers with air-dry densities between 800 and 1120 kg m^{-3} and 15% moisture content. The woods in the category are inherently resistant to decay. Timbers of air-dry density from 720 to 880 kg m^{-3} and a moisture content of 15% are labelled as medium hardwoods (MHW). The group of woods are moderately durable. Light hardwoods (LHW) have air-dried densities between 400 and 720 kg m^{-3} and 15% moisture and are non-durable. LHW is suitable for lightweight construction, low-stress flooring, paneling, non-structural elements, and general-purpose timber applications [15].

Softwood is sourced from gymnosperm trees. Only a limited number of commercially significant softwood species are available in Malaysia, including *damar minyak* (*Agathis spp*.), *podo* (*Dacrycarpus imbricatus, Nageia spp*., and *Podocarpus spp*.), and *sempilor* (*Falcatifolium falciforme, Dacrydium spp*., and *Phyllocladus spp*.) [16]. On the other hand, *Kembang* Semangkuk, Mempisang, and *Pulai* are LHW. The timbers from the trees are non-durable when exposed to outdoor elements. Nonetheless, timber is versatile, and utilized in various applications, including light construction, plywood, veneers, furniture, and decorative items. The LHW from the trees are also well-suited for posts, beams, joists, rafters, pallets, and non-structural members [17]. Moreover, Malaysian plywood manufacturers rely heavily on the Kembang Semangkuk, Mempisang, and Pulai trees as their primary raw material.

Sandwich boards (SB) consist of three segments: a core, two outer layers, and a protective covering. Thinly sliced LHW veneers are employed as the surface layers of SB. SB strength and stiffness are from the core segment, while protection and aesthetics are contributed by the surface layers. SB production requires a significant amount of wood, a limited and expensive natural resource. Consequently, alternative materials that are abundant, cheap, and environmentally friendly are necessary.

The current study aimed to evaluate the physical, mechanical, and surface soundness of SB manufactured from oil palm trunk particleboard (OPTPB) core and LHW veneer surfaces. This study also determined the effects of veneer species and press temperature on the SB performance. The findings might offer a sustainable and economic alternative by effectively employing the abundant and underutilized OPT [13].

2.0 MATERIALS AND METHODS

2.1 Materials

In this study, OPTPB and veneers derived from LHW species, such as Kembang Semangkuk (KS), Mempisang (MP), and Pulai (PU) were employed. The veneers were 0.7 mm thick and were supplied by the Malaysia Veneer Plywood (MVP) sawmill in Mentakab, Pahang. The thickness of the veneers was measured at four corners with 0.01 mm accuracy.

In this study, the veneers were conditioned in a conditioning room at 20 ± 2℃ and 65 ± 5% relative humidity (RH). During the glue spreading, the final average moisture content was anticipated at approximately 9%–10%. The OPT employed in this study were supplied by Federal Land Development Authority (FELDA) Ulu Jempul, Pahang, and transported to the workshop. On the other hand, the urea-formaldehyde (UF) and phenol formaldehyde (PF) were supplied by the Malayan Adhesive and Chemicals Sdn. Bhd., Shah Alam, Selangor.

2.2 Manufacturing the Board

The OPTPB core employed in the current study was manufactured with a targeted density and thickness of 0.70 g cm^{-3} and 12 mm, respectively. The particles were blended with 10% UF resin relative to the dry biomass. A homogeneous OPT was placed in an approximately 340 mm × 340 mm mould, cold pressed for 30 seconds, and hot pressed at 165℃ for 6 minutes.

During the SB lamination, veneers were spread with PF resin at a 300g m^{-2} spread rate, with an initial PF viscosity of 0.5 poise and resin and flour viscosity of 12 poises. Following the application of the resin on the loose side of the veneers, they were laminated on both surfaces of the particleboard. Subsequently, each board was cold pressed for 10 minutes to allow distribution of them on the particleboard.

The OPTPB was utilized as the core layer of the SB. During pressing, two 12 mm thick steel stoppers were placed on both sides of the assembled mat to regulate the final thickness of the board. The mats were pressed with the plates heated to 120℃ or 130℃ at 150 psi.

The veneer species and temperature are listed in Table 1.

Table 1 The veneer species with different pressing temperatures applied during the manufacture of the SB

No	Veneer Species	Temperature (⁰C)
1	Kembang semangkuk	120
2	Kembang semangkuk	130
3	Mempisang	120
4	Mempisang	130
5	Pulai	120
6	Pulai	130

2.3 Evaluating the Manufactured Boards

All boards were left to condition until they reached a constant mass before testing at a temperature of 20 ± 20℃ and 65 ± 5% of relative humidity. The mechanical and physical properties of the particleboard specimens were evaluated according to the Japanese Industrial Standards (JIS) (2003). The particleboard assessment parameters were also adhered to, including modulus of elasticity (MOE) and modulus of rupture (MOR), internal bond (IB), and thickness swelling (TS).

2.3.1 Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)

A bending test was carried out to determine the modulus of rupture (MOR) and modulus of elasticity

(MOE). MOR measures a material's breaking stress, while MOE indicates its stiffness. The samples were 280 mm × 50 mm × 12 mm. The load was applied at about 10 mm per minute. The equation of the bending strength, BS, is

$$\text{BS} = \frac{3PL}{2bt^2} \tag{1}$$

where P is the maximum load, L is the span, b is the width of test piece, and t is the thickness of test piece.

2.3.2 Internal Bonding (IB)

The IB test measures tensile strength perpendicular to the sample surface, following JIS A5908:2003 standards. Each specimen of 50 mm × 50 mm × 12 mm was lightly sanded to remove loose particles, then attached to test blocks with epoxy resin. Testing was conducted after 24 hours to allow the resin to cure. A tension loading speed of about 2 mm/min was applied until the maximum force was reached using equation (2).

$$\text{IB} = \frac{P'}{2bL} \tag{2}$$

where P is the maximum load at the time of failing force, b is the width of test piece and L is the length.

2.3.3 Surface Soundness (SS)

A 50 mm × 50 mm square board sample was assessed for surface soundness (SS). A circular groove was cut into the surface layer of the specimen. According to EN 311 (2003), the inside width of the grooves should measure ∅ 35.7 mm and at a 0.3 ± 1 mm depth into the substrate. The sample board was evaluated at a constant speed of 60 seconds until it failed or delaminated. The SS was calculated as equation (3).

$$\text{SS} = \frac{F}{A} \tag{3}$$

where F is the maximum force, and A is the area 1000.

2.3.4 Thickness Swelling (TS)

TS was measured by assessing the sample thickness before and after water immersion. A linear gauge was used to measure the center of each test piece at the diagonal intersection. The samples were then submerged horizontally, about 3 cm below the water surface, in water maintained at 20±1°C for 24 hours. After immersion, excess water was wiped off, and the thickness was remeasured according to equation below:

$$\text{TS (\%)} = \frac{(t_2 - t_1)}{t_1} \times 100 \tag{4}$$

where t_1 is the thickness before immersion in water, and t_2 is the thickness after immersion in water.

3.0 RESULTS AND DISCUSSION

3.1 The Properties of the Sandwich Board from Different LHW Veneers

Table 2 summarizes the comparative performance of the KS, MP, and PU utilized in the SB manufactured in the present study under different temperature conditions. The physical and mechanical properties, including MOR, MOE, IB, surface soundness (SS), and TS, performances of the boards were evaluated. The MP exhibited excellent MOR, MOE, and SS results across different temperatures. On the other hand, the PU demonstrated the highest TS increment compared to the other species. The Kembang Semangkuk (KS) specimen recorded a higher IB than the Mempisang (MP) and Pulai (PU) species. Based on the results, the MOR generally decreases with increasing TS when the temperature rises from 120℃ to 130℃ for all species. The MP sandwich board produced at 120℃ also met all minimum requirements specified by the JIS.

Table 2 The mechanical and physical properties of the SB

VS	Temp (℃)	MOR (MPa)	MOE (MPa)	IB (MPa)	SS (MPa)	TS (%)
KS	120	33.67 (2.25)	4152 (462)	1.14 (0.17)	0.97 (0.11)	18.90 (2.22)
KS	130	29.49 (2.18)	4159 (288)	1.01 (0.20)	0.63 (0.13)	24.81 (2.90)
MP	120	41.91 (2.38)	5017 (128)	1.24 (0.14)	1.15 (0.13)	23.43 (4.41)
MP	130	39.55 (4.44)	4921 (181)	1.16 (0.18)	0.68 (0.03)	24.74 (2.86)
PU	120	30.49 (2.66)	4225 (259)	1.15 (0.10)	0.75 (0.08)	20.46 (3.01)
PU	130	29.81 (3.17)	4155 (235)	1.18 (0.11)	0.74 (0.04)	27.67 (1.62)
JIS		30	4000	0.3	EN >1.0	12

[Note: VS = Veneer Species, JIS = JIS A5908:2003 (Type 30-15) and EN = EN 311 (2003), KS = Kembang semangkuk. Mp = Mempisang, PU = Pulai]

3.2 Statistical Significance

An analysis of variance (ANOVA) of the different LHW species veneers and temperature effects on the SB properties was performed. The results are listed in Table 3. The MOR, MOE, and SS significantly varied among the LHW veneers. Conversely, the IB and TS were not substantially different. Although temperature considerably affected the SS of the SB produced in this study, it did not influence the MOE, IB, TS, and MOR of the SB. Nonetheless, MOR and TS demonstrated significant interactions between LHW species and temperature.

Table 3 The ANOVA summary of the effects of different LHW species veneers and temperatures on the SB properties

SOV	Df	MOR	MOE	IB	SS	TS
Species (S)	2	28.437*	15.781*	1.339 *ns*	7.055*	1.613 *ns*
Temp (T)	1	3.731*ns*	0.158 ns	0.801 *ns*	51.006*	17.062*
S × T	2	0.658*ns*	0.054 ns	0.048 *ns*	12.112*	2.325 *ns*

(Note: SOV = source of variance, Df = degree of freedom, * = significant difference at $p < 0.05$, *ns* = not significant at $p > 0.05$), Temp = temperature

3.3 The Effects of Veneer Species on the Sandwich Board

Figure 1 illustrates the mechanical and physical attributes of the SB manufactured with different veneer species. The MP sample exhibited the highest MOR (40.73 MPa), MOE (4969 MPa), IB (1.19 MPa), and SS (0.92 MPa) values, indicating that denser veneers enhance structural integrity and mechanical strength. This aligns with previous studies showing a direct correlation between veneer density and mechanical performance in composite panels [18] [19].

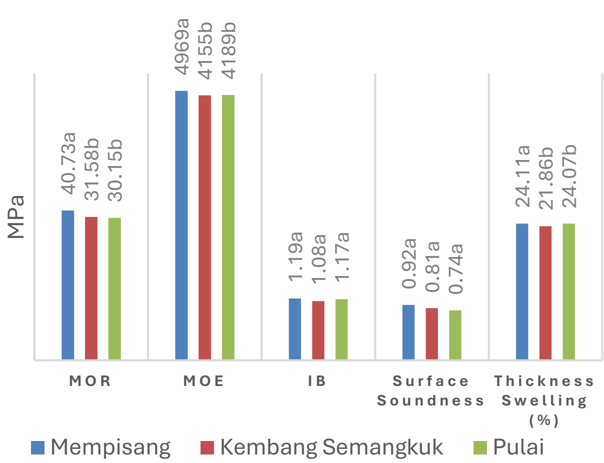


Figure 1 The effects of species on bending properties, TS, and SS for SB

A comparative analysis of the PU and KS samples further illustrates the impact of veneer species on SB properties. While PU exhibited mechanical properties like KS in terms of MOR, IB, and SS, its slightly higher MOE suggests that density variations within the species contribute to enhanced stiffness. KS, which has the lowest values for most mechanical parameters, demonstrated the highest TS (21.86%), signifying that lower-density veneers result in greater dimensional stability. This trend highlights the trade-off between mechanical strength and swelling resistance in different veneer species [20].

The correlation coefficients in Table 4 further reinforces these observations, demonstrating that while veneer species alone may not significantly influence mechanical properties (MOR, MOE, IB, and SS), veneer density plays a critical role. Higher-density veneers contribute to improved mechanical attributes, as previously reported in studies on oil palm trunk (OPT) SB [21]. This suggests that optimizing veneer density, rather than solely focusing on species selection, is crucial for enhancing SB performance.

Table 4 The correlation coefficients of the species and temperature on SB properties

Variable	MOR	MOE	IB	SS	TS
Species	−0.086*ns*	0.017*ns*	0.244*ns*	−0.116ns	0.365*
Temperature	−0.274*ns*	−0.087*ns*	−0.188*ns*	−0.689**	0.576**

(Note: *ns* = no significant correlation at $p > 0.05$, * = significant at $p < 0.05$, and ** = highly significant at $p < 0.01$)

3.4 The Effects of Temperature on the SB

Figure 2 presents the influence of processing temperature on the mechanical and physical properties of SB. The findings reveal a decline in modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB), and shear strength (SS) as the temperature increased from 120℃ to 130℃. This reduction suggests that excessive thermal exposure may adversely affect the integrity of the SB, potentially due to resin over-curing or the degradation of adhesive bonding between particles [22]. The decrease in IB further supports this observation, as internal bonding is highly dependent on the effectiveness of resin curing.

In contrast, thickness swelling (TS) exhibited an increasing trend with rising temperature, indicating a higher susceptibility to moisture absorption [23], who reported a decrease in TS at higher temperatures, may be due to variations in resin formulation, curing conditions, and pressing parameters. Such differences underscore the complexity of temperature effects on SB properties and highlight the necessity of optimizing processing conditions to achieve a balance between mechanical performance and dimensional stability.

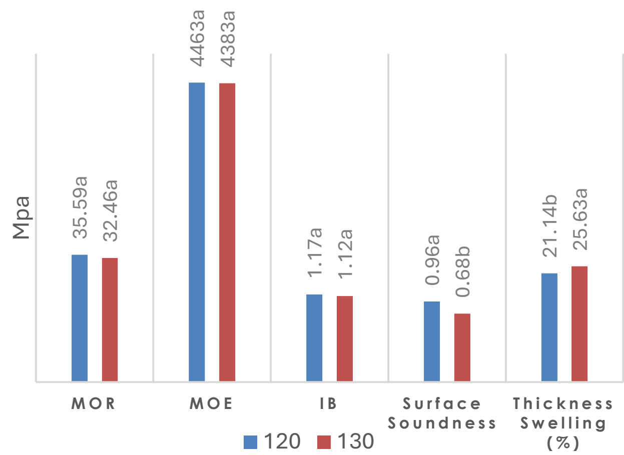


Figure 2 The effects of bending properties, TS, and SS on the SB temperature

4.0 CONCLUSION

This study investigated the effects of different light hardwood veneer species and pressing temperatures on the mechanical and physical properties of oil palm trunk (OPT) sandwich boards (SB). The findings indicate that increasing the pressing temperature from 120℃ to 130℃ negatively impacted the board's mechanical properties, with reductions observed in modulus of rupture (MOR), modulus of elasticity (MOE), and surface soundness (SS). However, thickness swelling (TS) increased at higher temperatures, suggesting that excessive heat may weaken adhesive bonding and compromise dimensional stability.

Furthermore, the choice of veneer species significantly influenced SB performance. Mempisang (MP), the highest-density species among those tested, demonstrated superior MOR, MOE, and SS values, highlighting the advantage of using denser wood species for improved mechanical strength. In contrast, Kembang Semangkuk (KS) and Pulai (PU) exhibited lower mechanical performance, with PU also recording the highest TS. The results confirmed that veneer density plays a crucial role in determining board strength and durability.

Overall, the optimal combination for SB fabrication was found to be MP veneer at a pressing temperature of 120°C, as it met Japanese Industrial Standard (JIS) requirements for MOE, MOR, and SS, except for TS. These findings emphasize the importance of optimizing pressing conditions and selecting appropriate veneer species to enhance SB performance. Future research should explore additional veneer species, alternative adhesives, and extended durability testing to further refine the SB production process and broaden its application potential.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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