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Influence of resin content on the properties of particleboard made from different parts of oil palm biomass

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ABSTRACT: The increasing availability of oil palm biomass offers significant potential as a sustainable raw material for particleboard, particularly for non-structural furniture and interior applications traditionally dominated by wood-based panels. This study investigated the physical and mechanical properties of particleboards manufactured from three oil palm residues; trunks (OPT), fronds (OPF), and empty fruit bunches (EFB) using urea-formaldehyde resin at contents of 8%, 10%, and 12%. All boards were produced at a target density of 700 kg/m³ and hot-pressed at 165°C for 360 seconds. Particleboards fabricated from OPT satisfied the minimum mechanical requirements of the standard at all resin contents, indicating their suitability for furniture components such as panels, shelving, and carcass materials. OPF-based boards achieved acceptable strength only at the highest resin level (12%), while EFB-based boards failed to meet the required mechanical criteria regardless of resin content. None of the particleboards met the dimensional stability standard, with 24h thickness swelling values exceeding the permissible <12% limit under water immersion. Overall, the results demonstrate that oil palm trunk residues show the greatest potential for value-added particleboard production in furniture and interior applications, supporting the broader objective of reducing reliance on solid wood resources in the wood-based panel industry.

Keywords: Oil palm biomass, Oil Palm Trunk, Particleboard, Resin content

Yağ palmiyesi biyokütlesinin farklı kısımlarından yapılan yonga levhanın özellikleri üzerindeki reçine içeriğinin etkisi

ÖZ: Yağ palmiyesi biyokütlesinin artan mevcudiyeti, özellikle geleneksel olarak ahşap bazlı panellerin hakim olduğu yapısal olmayan mobilya ve iç mekan uygulamaları için, yonga levha üretimi için sürdürülebilir bir hammadde olarak önemli bir potansiyel sunmaktadır. Bu çalışmada, üç yağ palmiyesi kalıntısından (gövdeler (OPT), yapraklar (OPF) ve boş meyve salkımları (EFB)) üretilen yonga levhaların fiziksel ve mekanik özellikleri, %8, %10 ve %12 oranlarında üre-formaldehit reçinesi kullanılarak incelenmiştir. Tüm levhalar 700 kg/m³ hedef yoğunluğunda üretildi ve 165°C'de 360 saniye süreyle sıcak preslenmiştir. OPT'den üretilen yonga levhalar, tüm reçine içeriklerinde standardın minimum mekanik gereksinimlerini karşılamış, bu da paneller, raflar ve karkas malzemeleri gibi mobilya bileşenleri için uygun olduklarını göstermektedir. OPF bazlı levhalar kabul edilebilir mukavemete ancak en yüksek reçine seviyesinde (12%) ulaşırken, EFB bazlı levhalar reçine içeriğinden bağımsız olarak gerekli mekanik kriterleri karşılayamadı. Parçacık levhaların hiçbiri boyut kararlılığı standardını karşılamadı; 24 saatlik kalınlık şişme değerleri su altında batırıldığında izin verilen <%12 sınırını aştı. Genel olarak, sonuçlar, yağ palmiyesi gövdesi kalıntılarının mobilya ve iç mekan uygulamalarında katma değerli yonga levha üretimi için en büyük potansiyeli gösterdiğini ve bu durumun, ahşap bazlı panel endüstrisinde katı ahşap kaynaklarına bağımlılığı azaltma yönündeki daha geniş hedefi desteklediğini göstermektedir.

Anahtar kelimeler: Yağ palmiyesi biyokütlesi, Yağ palmiyesi gövdesi, Yonga levha, Reçine içeriği

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1 Introduction

The wood-based panel industry has experienced a decline in wood supply attributed to new legislative regulations on wood utilisation in specific countries, heightened environmental concerns, and the global demand for wood raw materials. To address the challenges associated with wood use in particleboard manufacturing, it is imperative to explore abundant feedstocks derived from renewable agricultural residues and wood byproducts as a substitute, thereby reducing negative environmental impacts. Agricultural wastes, considered biomass resources, have been extensively utilised and converted into various beneficial products. These applications address environmental issues and enhance pollution management.

Among agricultural commodities, oil palm generates a large and regionally concentrated biomass stream; production has expanded significantly in recent decades and is dominated by Indonesia and Malaysia (Zaimi et al., 2025; Zakaria et al., 2024). More important than absolute production figures, however, are the waste-management challenges associated with oil palm cultivation and processing. A high proportion of oil palm biomass; empty fruit bunches (EFB), mesocarp fibre (MF), palm kernel shells (PKS), oil palm trunks (OPT), fronds (OPF), and palm oil mill effluent (POME) is currently under-utilised (Rajakal et al., 2024; Manimaran et al., 2025). Studies report that only a small fraction of available biomass is repurposed, leaving substantial quantities classified as waste and creating environmental and logistical burdens for plantations and mills.

Efficient utilisation of oil palm residues can deliver multiple benefits, reducing disposal problems, generating new revenue streams, and supplying low-cost feedstock for industrial applications. Converting oil palm biomass into particleboard addresses both resource scarcity in the wood-panel sector and the need for cost-effective, sustainable building materials. Prior work has demonstrated potential performance trade-offs when substituting agricultural residues for wood particles; therefore, material selection, particle preparation, and binder formulation are critical to achieving boards that meet technical standards (Ajayi et al., 2025; Zaimi et al., 2025).

The present study aims to evaluate the physical and mechanical properties of particleboards manufactured from three oil palm residues, namely oil palm trunk (OPT), oil palm frond (OPF), and empty fruit bunch (EFB). Unlike previous studies that focused on single biomass sources or alternative adhesives, this work systematically compares OPT, OPF, and EFB under identical processing conditions to identify their suitability for particleboard applications. This particleboard produced from urea-formaldehyde (UF) with three resin loadings (8%, 10%, 12%). Physical properties (thickness swelling, water absorption) and mechanical properties (modulus of rupture, modulus of elasticity, internal bond) were measured to assess the technical viability of these biomass residues as partial or full substitutes for conventional wood particles. The results are discussed with respect to process optimization and the potential role of oil palm-derived particleboards in sustainable materials strategies and circular-economy applications.

2 Material and Method

2.1 Material

The materials utilized in the production of particleboard (PB) included 25 years of oil palm trunk (OPT), oil palm frond (OPF), and oil palm empty fruit bunch (EFB). These biomass resources were possessed from an oil palm plantation in Ulu Jempul, and the Jengka Advance Renewable Energy Plant (JAREP) in Jengka 9. The resin used was urea formaldehyde (UF), bought from Aica Malaysia Sdn. Bhd., Senawang.

OPT were debarked, cut into blocks, and processed with a disc flaker to produce uniform strands. The petiole and leaflets of OPF were removed from the fronds. The fronds were initially chipped with a chipper to reduce their size before particle preparation. Both OPF and EFB were processed into particles using a knife ring flaker separately, which ensured consistent particle geometry suitable for panel manufacturing. The resulting particles were screened with a vibrating screener to separate and remove fine fractions, as excessive fines could negatively influence resin distribution and impair the mechanical properties of the particleboard. The screened particles within the size range of <2.0 mm to 0.5 mm were then oven-dried at 60°C for 24 hours to reduce their moisture content (MC) to below 5%.

2.2 Method

Dried particles were used from OPT, OPF and EFB as the primary raw material for board fabrication. The biomass was blended with urea-formaldehyde (UF) resin using a particleboard mixer, with solid content 64.5% and resin contents adjusted to 8%, 10%, and 12% based on dry particle weight. To avoid adhesion during mat formation and pressing, a silicone release agent was applied to the surfaces of the metal plates. The resin-coated particles with 12% MC then manually distributed into wooden moulds measuring 340 mm × 340 mm. A preliminary cold pressing was carried out for 60 seconds to consolidate the mat and minimize particle displacement. This was followed by hot pressing at 165 °C for 6 minutes to achieve a target thickness of 12 mm. The hot-pressing process was conducted using three sequential pressure stages: the particleboard mat was initially pressed at 1800 psi for 180 seconds, followed by 1200 psi for 120 seconds, and finally 800 psi for 60 seconds. The pressed boards were subsequently conditioned for seven days at 20 ± 2 °C and 65 ± 5% relative humidity prior to physical and mechanical evaluation.

The evaluation of properties including thickness swelling (TS), water absorption (WA), modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IB) was conducted in accordance with the JIS A 5908:2003 standard (JIS, 2003).

Regardless of the particleboard variant, two replicate boards were produced for each experimental condition. Internal bond strength, thickness swelling, and water absorption were evaluated using 50 mm × 50 mm specimens, with ten repetitions conducted for each test. The modulus of rupture (MOR) and modulus of elasticity (MOE) were assessed using 230 mm × 50 mm specimens, with six repetitions performed for each mechanical properties.

The data were subjected to analysis of variance (ANOVA) using the Statistical Package for the Social Sciences (SPSS) software (version 28, IBM, Armonk, NY, USA). Descriptive statistical analysis was conducted to obtain mean values and corresponding standard deviations, and the standard deviations were used to construct the error bars presented in the graphical results. Post hoc comparisons among group means were carried out using Duncan's Multiple Range Test (DMRT) to identify statistically significant differences at a confidence level of $p \leq 0.05$. In addition, the measured physical and mechanical properties were evaluated against the minimum requirements specified in the JIS A 5908 standard (JIS, 2003).

3 Results and Discussion

Table 1 presents the ANOVA results for the effects of material type and resin content on the physical and mechanical properties of particleboards produced from different oil palm biomass sources. Both factors significantly influenced WA, TS, MOR, MOE, and IB ($p < 0.01$), indicating that particleboard performance is strongly governed by the intrinsic characteristics of the raw material and the degree of resin bonding. The significant interaction observed between material type and resin content for most properties further suggests that the response of particleboard performance to resin addition is material-specific, a trend commonly reported in biomass-based particleboards derived from heterogeneous lignocellulosic resources.

Table 1 Summary of ANOVA findings at P < 0.05 concerning the interaction effects of material and resin content on particleboard qualities

SOV	WA	TS	MOR	MOE	IB
Material (M)	0.000**	0.000**	0.000**	0.000**	0.000**
Resin Content (RC)	0.000**	0.000**	0.000**	0.000**	0.000**
M*RC	0.013*	0.000**	0.002*	0.003*	0.168*ns*

*SOV source of variance, ** highly significant p < 0.01, * significant p < 0.05, ns not significant p > 0.05*

3.1 Analysis on TS and WA of PB

Table 2 presents a summary of the TS and WA values of particleboard composed of EFB, OPF, and OPT, bonded with varying resin contents. At identical resin content, particleboard composed of OPT exhibits superior TS values compared to that made from EFB and OPF. The TS values of the EFB particleboard bonded at varying resin contents range from 15.27% to 35.85%, whereas those of OPF and OPT range from 20.52% to 22.06% and 32.20% to 39.10%, respectively. In contrast to EFB, both OPF and OPT possess a significant proportion of parenchymatous tissues (thin-walled cells with large lumens) that are inclined to absorb and retain greater amounts of water (Abdul Khalil et al. 2008). Consequently, OPF and OPT particleboard exhibited greater water absorption than EFB particleboard. The TS values diminished as the resin content increased (Figure 1). A comparable observation was noted for WA values, which diminished with increasing content (Figure 2). Nonetheless, none of the particleboard manufactured in this study conformed to the maximum permissible TS value of < 12% as specified in JIS A 5908 standard (JIS, 2003). (Figure 1). The resin content is the primary determinant influencing the thickness swelling of particleboard (Boruszewski et al. 2022). Hong et al. (2017) stated that post-curing, the UF resin developed a rigid crosslinked structure that is impermeable to water. A greater resin content results in an increased proportion of hardened structures, leading to a more dimensionally stable particleboard.

Table 2. TS and WA of various oil palm biomass types in particleboard

Type	Material	Resin Content (%)	Water Absorption (%)	Thickness Swelling (%)
1	EFB	8	98.93±7.89[b]	35.85±2.97[e]
2		10	86.48±4.10[a]	26.69±2.14[c]
3		12	81.06±5.77 [a]	15.27±0.91[a]
4	OPF	8	123.70±9.60[d]	22.06±2.54[b]
5		10	104.48±12.73[bc]	21.56±4.84[b]
6		12	80.98±8.24 [a]	20.52±5.47[b]
7	OPT	8	108.41±12.03[c]	39.10±2.09[f]
8		10	105.10±10.17[bc]	35.61±2.92[e]
9		12	105.10±7.58[bc]	32.20±4.23[d]

Means followed by the different superscript letters in the same column are significantly different at p ≤ 0.05; EFB = empty fruit bunches, OPF = oil palm front; OPT = oil palm trunk

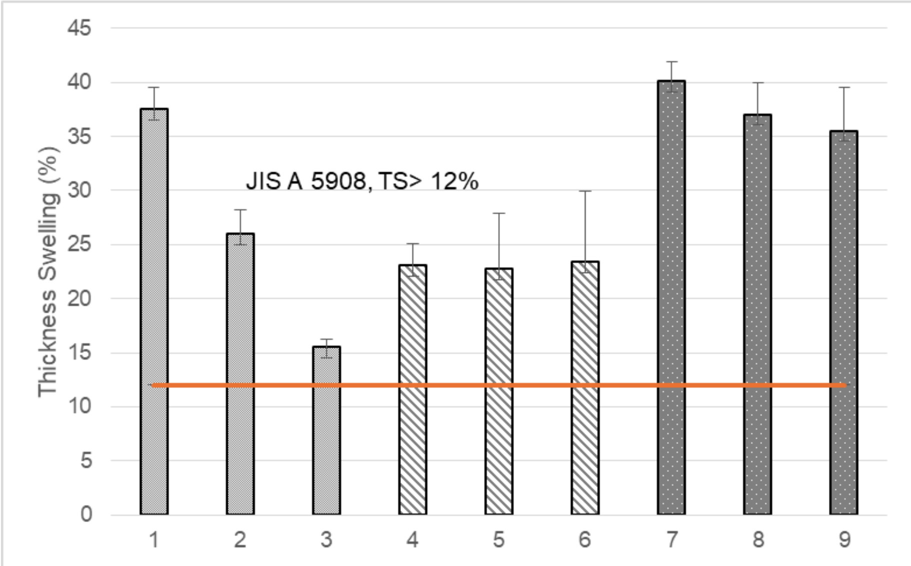

Figure 1. TS of various oil palm biomass types in particleboard compared to JIS A 5908 (2003)

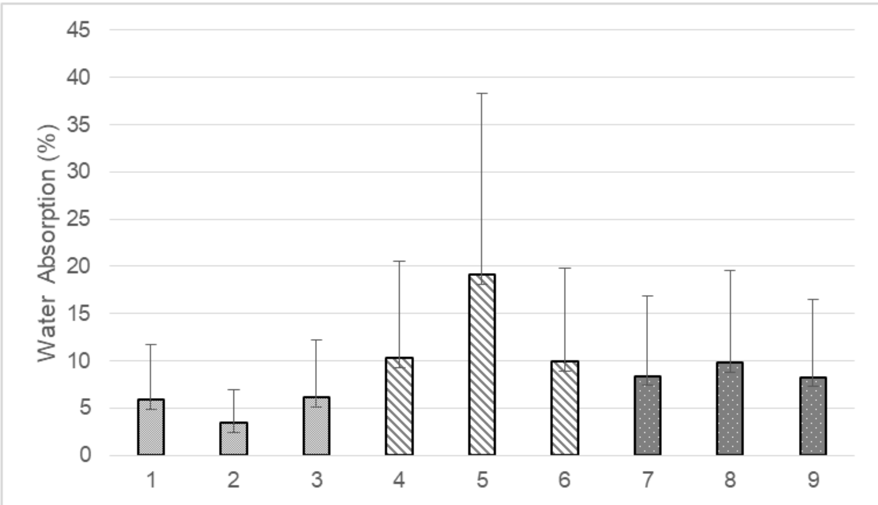

Figure 2. WA of various oil palm biomass types in particleboard

3.2 Mechanical properties of PB

The mechanical properties, including MOR, MOE, and IB of the particleboard, are presented in Table 3. OPT particleboard exhibited markedly superior MOR and MOE relative to its OPF and EFB counterparts. Concurrently, EFB particleboard demonstrated the least bending strength among the three particleboard varieties. A comparable trend was also noted for IB. The observation may be ascribed to the bulk density of the materials utilized in particleboard production. According to a study by Zakaria et al. (2021), the bulk densities of EFB, OPF, and OPT particles were 670 kg/m^3, 560 kg/m^3, and 460 kg/m^3, respectively. Materials with lower bulk density can attain a more compact structure when subjected to hot pressing (Boruszewski et al. 2016). A more compact structure will diminish the voids present in the particleboard, thereby enhancing its mechanical properties. Lee et al. (2015) reported that particleboard with lower bulk density can achieve a higher compaction ratio and, consequently, superior strength properties. The subpar mechanical properties of the EFB particleboard may be attributed to residual oil on the EFB fibers (Norul Izani et al. 2012). The oil obstructs the uniform distribution of resin on the EFB fibers, resulting in inferior mechanical properties. Nonetheless, augmenting resin content markedly enhanced the mechanical properties of the particleboard. For example, when the resin content was elevated from 8% to 12%, the modulus of rupture (MOR) of the oriented strand board (OSB) rose from 22.15 MPa to 24.37 MPa, while the internal bonding (IB) increased from 1.66 MPa to 2.43 MPa. The resin content significantly affects the mechanical properties of the resulting particleboards (Barragàn-Lucas et al. 2019). With an increase in resin content, the particles achieved comprehensive resin coverage, resulting in enhanced bonding sites between particles and ultimately improving MOR, MOE, and IB (Ghalehno et al. 2013).

Table 3. Strength properties (MOR, MOE, IB) of various oil palm biomass types in particleboard

Type	Material	Resin Content (%)	MOR (MPa)	MOE (MPa)	IB (MPa)
1	EFB	8	5.00±0.30[a]	701±45.46[a]	0.07±0.01[a]
2		10	6.85±0.70[a]	888±59.57 [ab]	0.09±0.03[a]
3		12	9.19±0.03[b]	1050±56.62[b]	0.16±0.03 [ab]
4	OPF	8	13.52±2.22[c]	2212±481[c]	0.17±0.06[ab]
5		10	14.95±0.87[c]	2263±170[c]	0.33±0.13[b]
6		12	21.28±3.15[d]	3211±387[d]	0.70±0.25[c]
7	OPT	8	22.15±1.76[d]	2972±132[d]	1.66±0.27[d]
8		10	23.20±1.01[de]	3135±138[d]	1.76±0.31[d]
9		12	24.37±1.31[e]	3243±274[d]	2.43±0.41[e]

Means followed by the different superscript letters in the same column are significantly different at $p \leq 0.05$; EFB = empty fruit bunches, OPF = oil palm front; OPT = oil palm trunk

Figure 3 - 5 illustrates the MOR, MOE, and IB strength of panels produced with varying resin percentage. The JIS A 5908:2003 requires minimum MOR, MOE and IB values of 18 MPa, 3000 MPa and 0.3 MPa, respectively. All panels manufactured with OPT met the JIS standard criteria for MOR, MOE, and IB strength at all three levels of resin content. The panels manufactured from EFB and OPF failed to meet the criteria for MOR, MOE, and IB, except for the OPF variant with a resin content of 12%. The properties of particleboards manufactured with OPT exhibited a distinctly different pattern when compared to those produced with EFB and OPF. The particleboard containing 12% resin demonstrated the highest MOR and MOE when manufactured with OPT particles, reaching values of 24.37 MPa and 3243 MPa, respectively. At a consistent resin content, the values for MOR and MOE showed an initial increase during the production of particleboard using EFB and OPF. The same phenomenon was also observed with IB strength properties. The data suggests that an optimal resin content of 12% is necessary for the effective production of oil palm biomass particleboard. This finding aligns with Ayrilmis, Kwon, & Han (2012), who discovered that the mechanical properties of single-layer composite particleboards composed of 70 wt% wood particles and 30 wt% rice husk particles did not significantly improve in bending strength and modulus of elasticity with increased UF and PF resin contents, except at the 12 wt% resin content.

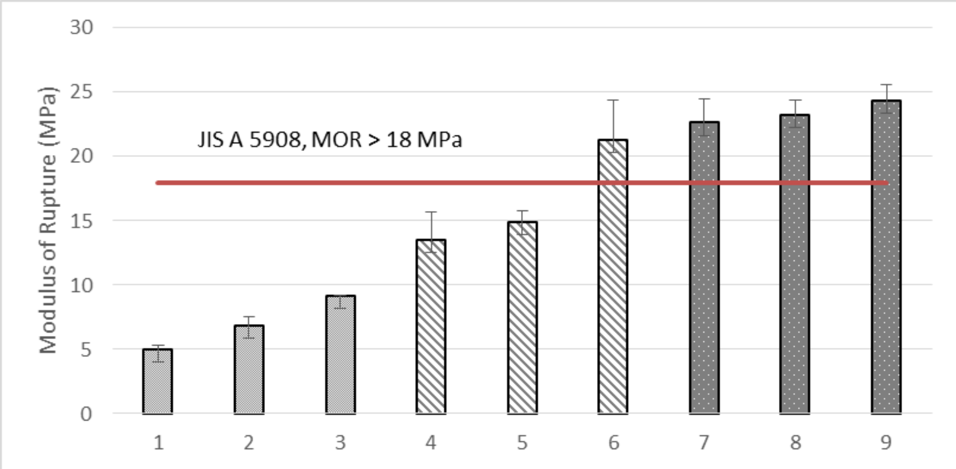

Figure 3. MOR of various oil palm biomass types in particleboard Compared to JIS A 5908 (2003)

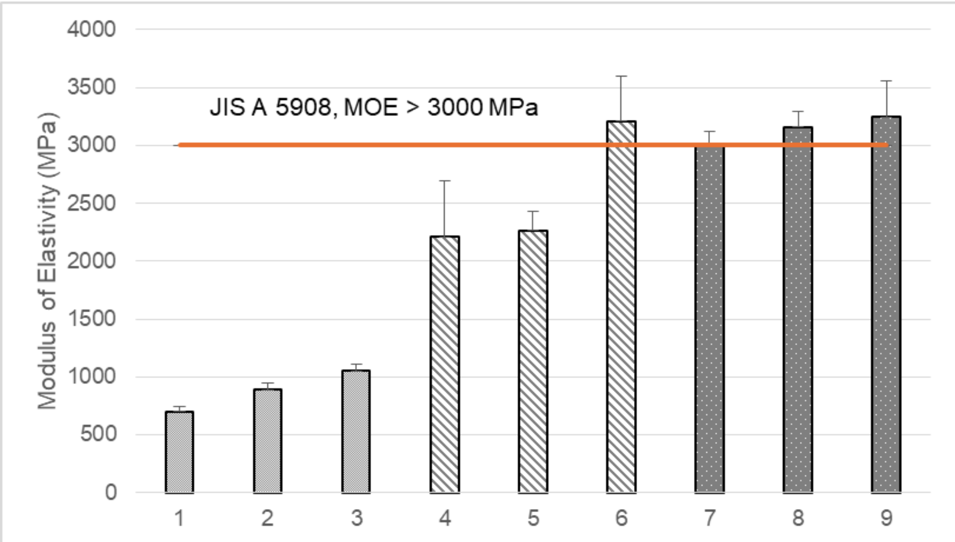

Figure 4. MOE of various oil palm biomass types in particleboard compared to JIS A 5908 (2003)

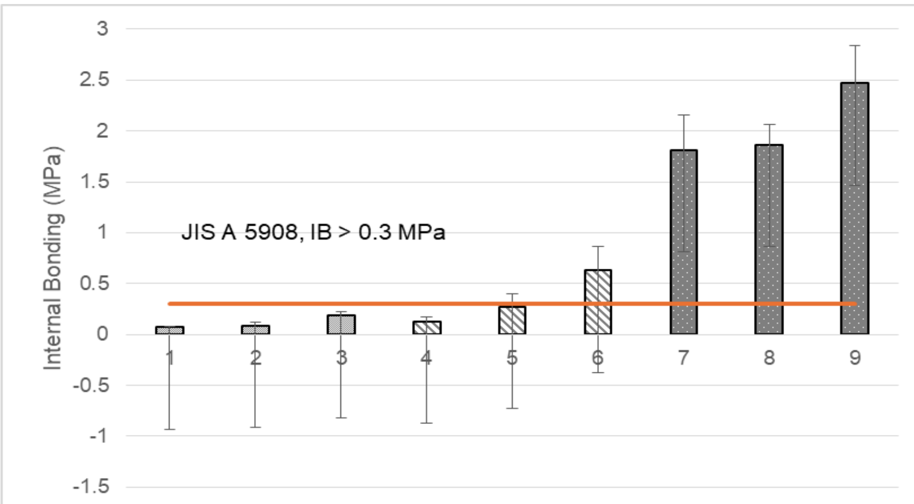

Figure 5. Internal bond strength of various oil palm biomass types in particleboard compared to JIS A 5908 (2003)

4. Conclusion

In this study, the physical and mechanical properties of particleboards manufactured from three oil palm residues, OPT, OPF, and EFB, were investigated. Based on the data obtained, the following conclusions can be drawn.

- This study confirms that resin content and biomass type significantly influence the physical and mechanical performance of particleboards produced from oil palm residues.
- Among the materials evaluated, oil palm trunk (OPT) demonstrated the greatest suitability as a raw material, consistently meeting the mechanical requirements of JIS A 5908 across all resin contents.
- In contrast, oil palm frond (OPF) particleboards achieved acceptable strength only at the highest resin level, while empty fruit bunch (EFB) boards failed to satisfy the standard requirements regardless of resin content, likely due to residual oil and poor interfacial bonding.
- Although increased resin content generally improved strength and dimensional stability, none of the panels complied with the standard limits for thickness swelling, indicating that moisture resistance remains the primary limitation.
- Overall, OPT shows strong potential for particleboard manufacturing, whereas OPF and EFB require additional treatments or material modification to enhance their performance.
- The effective utilization of oil palm biomass in panel products offers a sustainable pathway for improving resource efficiency and reducing agricultural waste in the wood-based panel industry.

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Author Contributions

Nurrohana Ahmad: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing, **Siti Noorbaini Sarmin**: Conceptualization, Formal Analysis, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing, **Lee Seng Hua**: Conceptualization, Data curation, Formal Analysis, Validation, Visualization, Writing – original draft, **Yusri Helmi Muhammad**: Conceptualization, Methodology, Project administration, Resources, Validation, Visualization, **Wan Mohd Nazri Wan Abdul Rahman**: Conceptualization, Data curation, Formal Analysis, Visualization, Writing – original draft, **Nur Sakinah Mohamed Tamat**: Conceptualization, Investigation, Project administration, Resources, Visualization, Writing – original draft.

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Conflict of interest statement

The authors declare no conflict of interest.

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