Pertanika J. Sci. & Technol. 34 (S2): 101 - 116 (2026)

PERTANIKA JOURNALS

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Strength and Durability Performance of Three-Layered *Leucaena leucocephala* Cement-Bonded Particleboard

Marzuki Ab. Rahman[1], Mohd Fakri Muda[1,4]*, Mohd Razmi Zainudin[1], Muhammad Isha Ismail[1], Farah Wahida Mohd Latib[1], Amminudin Ab Latif[1], Noor Safwan Muhamad[1], Wan Zukri Wan Abdullah[3], Herlien Dwiarti Setio[2], and Mohd Hisbany Mohd Hashim[3,4]

[1]*Faculty of Civil Engineering, Universiti Teknologi MARA Pahang Branch, 26400 Jengka, Pahang, Malaysia*
[2]*Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, 40132 Bandung, West Java, Indonesia*
[3]*Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*
[4]*3R: Rehabilitation, Repair and Retrofitting Group, Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*

ABSTRACT

A study was conducted to explore the durability of Cement-Bonded Particleboard (CBP) under external shading (free from direct sunlight and rain) and without shading (exposed to natural weathering) conditions prevalent in Malaysia. The three-layered CBP boards were manufactured in the laboratory using *Leucaena leucocephala* (LL) at a wood-to-cement ratio of 1:2.0. The boards were produced to target a density of 1300 kg/m3. All boards were produced using a combination of aluminium sulphate and sodium silicate. The effects of exposure duration and condition on the Modulus of Rupture (MOR), Modulus of Elasticity (MOE), and Internal Bond (IB) were evaluated at 30, 60, 120, and 300 days. The results revealed that the MOR, MOE, and IB values differed significantly across durations and exposures. From this study, LL proved suitable for manufacturing CBP for external exposure.

Keywords: Cement-bonded particleboard, durability, *Leucaena leucocephala*, strength

ARTICLE INFO

Article history:
Received: 18 June 2026
Accepted: 10 August 2026
Published: 30 September 2026

DOI: https://doi.org/10.47836/pjst.34.S2.09

E-mail addresses:
marzukiar@uitm.edu.my (Marzuki Ab. Rahman)
fakri@uitm.edu.my (Mohd Fakri Muda)
razmi74@uitm.edu.my (Mohd Razmi Zainudin)
isha@uitm.edu.my (Muhammad Isha Ismail)
farahwahidaml@uitm.edu.my (Farah Wahida Mohd Latib)
amminudin738@uitm.edu.my (Amminudin Ab Latif)
safwanmuhamad@uitm.edu.my (Noor Safwan Muhamad)
wanz@uitm.edu.my (Wan Zukri Wan Abdullah)
herlien@itb.ac.id (Herlien Dwiarti Setio)
hisbany@uitm.edu.my (Mohd Hisbany Mohd Hashim)
* Corresponding author

INTRODUCTION

In the Cement-Bonded Particleboard (CBP) industry, assessing the long-term performance of wood cement composites,

e-ISSN: 2231-8526

© Universiti Putra Malaysia Press

particularly in warm and humid climates, is crucial. This evaluation is essential to assess the boards' durability and reliability over time. According to the American Society of Testing Materials, ASTM (2017), durability is defined as a material, product, component, assembly, or construction's capacity to remain serviceable as intended with prudent maintenance during the design service life under anticipated internal and external environments. More specifically, Alexander et al. (2017) define durability as the loss (or retention) of mechanical or physical properties after exposure to the ageing process. This statement aligns closely with the findings of Ramage et al. (2017), who suggest that CBP may experience a loss of strength over time due to wood's susceptibility to degradation in highly alkaline environments, similar to cement paste. Therefore, CBP manufactured with cement as the binder may be susceptible to degradation, reducing service life. However, the boards durable in one place may not be durable in another environment (Iraldo et al., 2017). This is probably related to air temperature, relative humidity, rainy weather, and sunshine, which can cause the board to expand and contract. Although modern CBPs have much improved strength properties, the quality, durability, and rising construction costs pose new pressures on researchers and industry. It ensures the durability of construction material in the surrounding environment, especially in the Malaysian climate. Overall, wood-cement composites (such as CBP) present high durability against natural weathering or accelerated ageing, high dimensional stability, and high resistance against fire and biodegradation, such as fungi (Wiejak & Francke, 2021).

The long-term performance of wood-cement composites is influenced by both the inorganic binder (cement) and the organic material (wood). The alkaline nature of Portland Cement (PC) can be particularly damaging to wood, as it can degrade the cellulose cell walls within the cement matrix. However, recent studies suggest that using low-alkaline cement and surface coatings can significantly improve the durability of wood-cement composites. According to a study by Xie et al. (2020), adding surface coatings such as graphene oxide can enhance the mechanical and durability properties of wood-cement composites. Similarly, Wei and Meyer (2015) found that using low-alkali cement can significantly reduce wood degradation in the cement matrix. Note that wood-cement composites have been considered a durable material in severe exposure conditions. Therefore, their long-term stability must also be considered. As an ideal construction material, CBP's durability should be thoroughly tested. Moreover, the use of low-alkaline cement and surface coatings can greatly improve the performance and longevity of wood-cement composites.

Leucaena leucocephala (LL) appears to be a logical choice as a raw material for CBP manufacturing, given the industry's challenges with rubberwood supply. LL offers an alternative raw material and leverages its fast growth rate. Rubberwood is typically available as a by-product from rubber estates after a 25-year economic lifespan (Mead, 2005). Hence, incorporating fast-growing species such as LL can expedite production

compared with woody plants. LL is a leguminous tree species that usually reaches a height of 20 meters with a bole diameter ranging from 5 to 50 cm (Obiakara et al., 2023; Singh et al., 2022). Moreover, it is widely cultivated in tropical and subtropical regions such as Hawaii, Australia, and Southeast Asia. In Malaysia, LL, also known as *petai belalang*, is commonly used as a shading tree due to its rapid growth (the lead tree). *Petai belalang* has been successfully planted at the Malaysian Agricultural Research and Development Institute (MARDI) as part of replanting programs. Additionally, its leaves serve as food for certain animals.

To evaluate the performance of LL CBP, we exposed the specimens to two conditions prevalent in Malaysia: shading (protected from direct sunlight and rain) and non-shading (subjected to natural weathering). The exposure lasted up to 300 days, and no coating was applied to the test specimens. The study focuses on weight changes and the mechanical and physical properties of the CBP over the duration of exposure. Other than that, the evaluation of mechanical and physical properties adheres to the minimum requirements outlined in the Malaysian Standard, MS 544 (2013). This analysis aims to establish the relationship between the durability of LL CBP and environmental factors that may impact its strength properties. These factors are crucial for ensuring the economic viability and efficiency of CBP.

The durability of any building material is influenced by the surrounding environment in which it is utilised. Hence, the mechanical and physical properties of the CBP were assessed at 30, 60, 120, and 300 days of exposure to external conditions, both with and without shading. Consequently, the mechanical tests included determining the Modulus of Rupture (MOR), Modulus of Elasticity (MOE), and Internal Bond (IB), as specified by the standards MS 934 (2013) and MS 544 (2013). Additionally, the physical properties were evaluated, including density and dimensional stability, in terms of the CBP's length, width, and depth, before and after exposure. By studying the interplay between these environmental factors and the mechanical and physical properties of the LL CBP, we can gain valuable insights into its overall durability and performance. This knowledge will help enhance the quality and suitability of CBP for various applications in the construction industry.

METHODOLOGY

Raw Materials Preparation

The wood particles utilised in this study were sourced from 8-year-old LL or *Petai belalang* trees grown in Peninsular Malaysia. To adhere to standard specifications, an ordinary PC was employed as the binder, conforming to the Malaysian Standard, MS 522 (2013) for PC (Ordinary and Rapid Hardening). Cement accelerators, a combination of aluminium

sulphate and sodium silicate, were incorporated at 1.5% and 3% by weight of the cement. Additionally, tap water was used as the mixing medium for all formulations.

The logs, measuring 1.0 m in length with diameters ranging from 30 mm to 150 mm (including branches), were promptly debarked manually using a hammer. Subsequently, the logs were processed into uniform chips using a wood chipper machine. Following conventional particleboard production methods, the chips were further flaked using a knife-ring flaking machine. Note that the wood particles were air-dried for approximately two weeks to achieve a moisture content of 14%-18%. Maintaining this moisture content is vital to prevent fungal infestation, particularly for long-term storage.

After drying, the wood particles were screened to obtain particles of various sizes. Specifically, a screening machine segregated them into fine and coarse particles. The particles retained on the 0.5 mm and 1.0 mm screens were designated fine particles for the surface or outer layer. Meanwhile, those retained on the 2.0 mm screen were categorised as coarse particles for the core layer in producing three-layered CBP specimens. This approach corroborates the findings of previous research, which demonstrated an enhancement in bending strength and stiffness of three-layered boards (Mussi Alencar & de Melo Moura, 2019; Sam-Brew & Smith, 2015). Note that wood particles larger than 5.0 mm were re-flaked using a knife-ring flake machine to obtain smaller particles.

Sample Board Fabrication

The wood particles were carefully placed into the cement board mixer, and precise amounts of chemical additives and water were added. Thorough mixing ensued until a homogeneous consistency was achieved. Subsequently, PC was introduced, and the mixing process continued until complete integration was achieved. The resulting mixture was manually consolidated in the mould, and pressure was applied to compress the board until reaching a thickness of 10 mm. To facilitate proper curing, the boards were securely clamped for 24 hours and then placed in a hardening chamber maintained at 65 ± 3°C. After the designated period, the boards were removed from the moulds and transferred to a curing tank, where they cured for approximately one month. The curing tank maintained a controlled relative humidity of 83% to 96%, which was monitored with a wet-and-dry bulb thermometer and recorded daily. This is to ensure thorough and complete curing of the boards.

Following the curing phase, the CBP panels were carefully trimmed to the prescribed dimensions outlined in the Malaysian Standard for mechanical properties testing. The boards' mechanical properties were assessed per MS 544 (2013). Consequently, the board dimensions were standardised at 450 mm × 450 mm × 10 mm (length × width × thickness), with a targeted density of 1300 kg/m^3. To ensure reliable data, three replicate samples were prepared for testing, resulting in a total of 30 specimen boards. The board sample fabrication is summarised in Figure 1.



Figure 1. Summary of LL CBP fabrication samples

Mechanical Properties Testing

The testing methods for MOR, MOE, and IB evaluate the mechanical properties of CBP. MOR testing measures bending strength by applying force to a board supported at two points until it breaks, indicating its resistance to bending stresses. MOE assesses stiffness by measuring deformation under load and calculating the initial slope of the load-deflection curve. Both properties reveal the material's elastic properties under the flexural stress test, as shown in Figure 2a. Figure 2b shows the IB test, which determines the tensile strength perpendicular to the board's plane by pulling a glued block until the internal bond fails. This test provides insights into the adhesive strength and cohesion within the board.

Method of Analysis

The results obtained from this study were analysed using Analysis of Variance (ANOVA). To assess the impact of the exposure condition, an Independent-Samples T-Test was

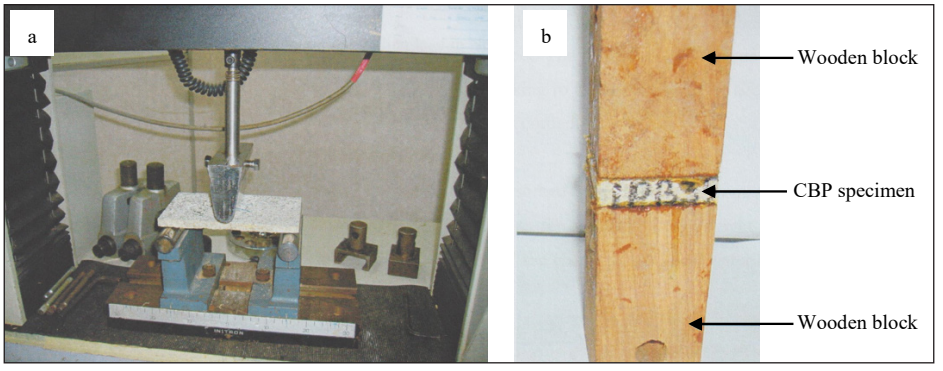

Figure 2. a) Flexural stress test and b) Internal bond test

conducted. Note that the dependent variables were subjected to a significant analysis based on the duration of exposure and exposure conditions. Through these statistical analyses, the study aimed to identify notable variations in the results and draw meaningful conclusions about the effects of exposure duration and conditions on the variables tested.

The performance of LL CBP was assessed by measuring its mechanical properties under different exposure conditions: external exposure with shading and external exposure without shading, and the evaluation period spanned 0, 30, 60, 120, and 300 days. Three essential properties were evaluated to understand the material's behaviour: MOR, MOE, and IB. MOR, represented by Equation 1, serves as a crucial indicator of a material's resistance to bending or flexural stresses, ensuring it remains intact without fracture. On the other hand, Equation 2 is the MOE, also known as Young's modulus, which gauges the material's stiffness and capacity to undergo elastic deformation when subjected to stress. Quantifying the relationship between stress and strain within the linear elastic range offers valuable insights into the material's structural integrity. Additionally, the IB in Equation 3 assesses the adhesive strength binding the particles or fibres within the material by dividing the tensile load, Fmax, by the cross-sectional area, A, of the CBP. This attribute directly influences the material's ability to withstand delamination or separation of its internal layers, ensuring durability and reliability under various conditions.

$$MOR = \frac{3FL}{2bd^2}, \quad [1]$$

$$MOE = \frac{WL^3}{4bd^3\delta}. \quad [2]$$

$$IB = \frac{F}{A} \quad [3]$$

RESULTS AND DISCUSSION

Performance of Exposed CBP

Table 1 and Table 2 present the mean values of the three key mechanical properties of the LL CBP panels exposed to the prevalent weathering conditions in Malaysia. The results are compared to the specifications outlined in the Malaysian Standard MS 544 (2013). These values provide insights into the performance of the LL CBP over the duration of 0 to 300 days. Similarly, Table 3 summarises the mean values of MOR, MOE, and IB for LL CBP panels. Meanwhile, Table 4 provides a comparative analysis of their performance compared to commercial boards. These values serve as references for assessing LL CBP's adherence to the Malaysian Standard MS 544 over time. Note that the data collected in both tables aid in understanding the durability and resilience of LL CBP under external weather conditions. Moreover, it allows for a comprehensive evaluation of its mechanical properties throughout the exposure period.

Effect of Duration Exposure on MOR

The results presented in Table 1 demonstrate a clear correlation between the exposure duration and the LL CBP's mechanical properties. Notably, the MOR of the boards remained relatively stable at the early stages of exposure to external conditions with shading. Furthermore, even after prolonged exposure, the strength properties of the LL

Table 1
Mechanical properties of LL CBP exposed to external conditions, CBP with shading

Duration (days)	MOR: LL CBP (MPa)	MOE: LL CBP (MPa)	IB: LL CBP (MPa)
0	11.76	3506	0.952
30	12.69	3733	0.961
60	11.30	3404	0.822
120	12.21	3462	0.752
300	14.78	4260	0.817
MS544	> 9.0	> 3000	> 0.5

Table 2
Mechanical properties of LL CBP exposed to external conditions, CBP without shading

Duration (days)	MOR: LL CBP (MPa)	MOE: LL CBP (MPa)	IB: LL CBP (MPa)
0	11.76	3506	0.952
30	11.73	3573	0.824
60	10.79	3288	0.620
120	10.74	3584	0.542
300	12.03	3453	0.605
MS544	> 9.0	> 3000	> 0.5

Table 3
Effect of exposure condition on the mechanical properties of LL CBP after 300 days of exposure

Test	Exposure	Mean (MPa)
MOR	Shading	12.55
	Without shading	11.41
MOE	Shading	3673
	Without shading	3481
IB	Shading	0.861
	Without shading	0.708

Table 4
Performance analysis between LL CBP and commercial boards (C-CBP)

Comparisons of LL CBP with Commercial Boards with Shading						
	MOR (MPa)		**MOE (MPa)**		**IB (MPa)**	
Duration (days)	LL CBP	C-CBP	LL CBP	C-CBP	LL CBP	C-CBP
0	11.76	12.09	3506	4318	0.952	0.99
300	14.78	13.88	4260	5917	0.817	1.66
Performance (%)	+ 25%	+14.8%	+21.5%	+37.0%	-15%	+67.7%

Comparisons of LL CBP with Commercial Boards Without Shading						
	MOR (MPa)		MOE (MPa)		IB (MPa)	
Duration (days)	LL CBP	C-CBP	LL CBP	C-CBP	LL CBP	C-CBP
0	11.76	11.66	3506	4696	0.952	1.07
300	12.03	8.06	3453	3260	0.605	0.78
Performance (%)	+ 2.3%	-30.9%	-1.5%	-30.6%	-36.5%	-27.1%

CBP were largely preserved. It is worth noting that during the exposure period, the boards exhibited exceptional resistance to warping, delamination, and twisting, indicating their robustness under external conditions. Figure 3 illustrates the progressive development of MOR in CBP boards exposed to external conditions with and without shading. After 30 days of shading, the MOR of the CBP increased notably, peaking at 300 days of exposure. This remarkable enhancement amounts to approximately 26% relative to the CBP's initial strength. Moreover, the observed increase in MOR is attributed to the continuous hydration of the cement matrix and the hardening process within the CBP. Several studies have previously reported similar strength improvements in CBP due to cement's ongoing hydration and hardening under ambient temperature conditions (Nazerian et al., 2011; Simatupang & Neubauer, 1993; Sudarmanto et al., 2022). It is crucial to note that sustained hydration of cement is facilitated by heat and moisture, especially in warm, humid climates such as those prevalent in Malaysia.

The MOR values decreased until 120 days of exposure, after which they gradually increased. The optimum MOR value of 12.03 MPa was achieved after 300 days of exposure,

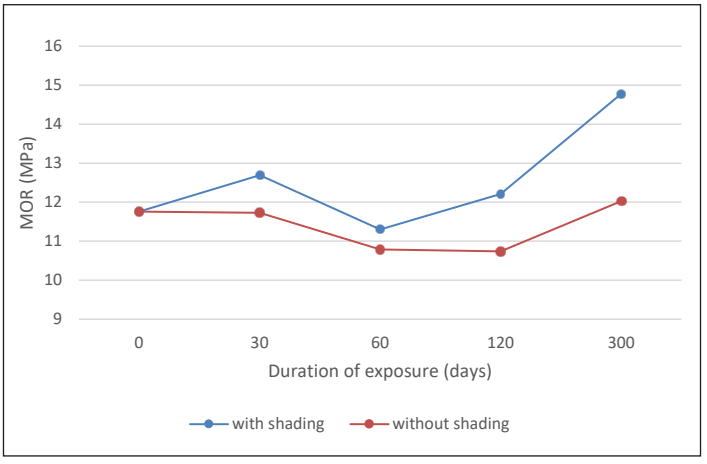

Figure 3. MOR of LL-CBP exposed to external conditions with and without shading for up to 300 days of exposure

representing a modest increase of approximately 2.3% compared to the initial strength. Importantly, this value remained above the 9.0 MPa requirement specified by MS 544. These findings suggest that continuous cement hydration and ongoing hardening contributed to the preservation and slight improvement of the MOR in the CBP. Nevertheless, further investigation is necessary to determine the specific duration for which the MOR might drop below the standard value. Hence, this investigation would provide valuable insights into the potential degradation of CBP's mechanical properties during extended exposure.

Effect of Duration Exposure on MOE

The impact of duration of exposure on the MOE properties of the CBP under external conditions with and without shading from the findings presented in Tables 1 and 2. These tables clearly demonstrate that the duration of exposure influenced the MOE values of the CBP. Notably, the MOE reached its optimum value towards the end of the exposure period. In particular, the maximum MOE was observed in the CBP specimens exposed to external conditions with shading, indicating an approximate 22% increase relative to the initial strength by the end of the exposure period. Figure 4 provides a graphical representation of the MOE development in the CBP specimens exposed to both shading and non-shading conditions.

The mean MOE values exhibited a trend like that of the MOR properties with respect to exposure duration. The MOE of the CBP increased after 30 days of exposure, with the maximum value attained at 300 days of exposure for both shading and non-shading conditions. As previously mentioned, this improvement in MOE is attributable to the cement's continuous hydration and hardening within the CBP. However, for CBP exposed to external conditions with shading, the MOE initially declined after 30 days of exposure.

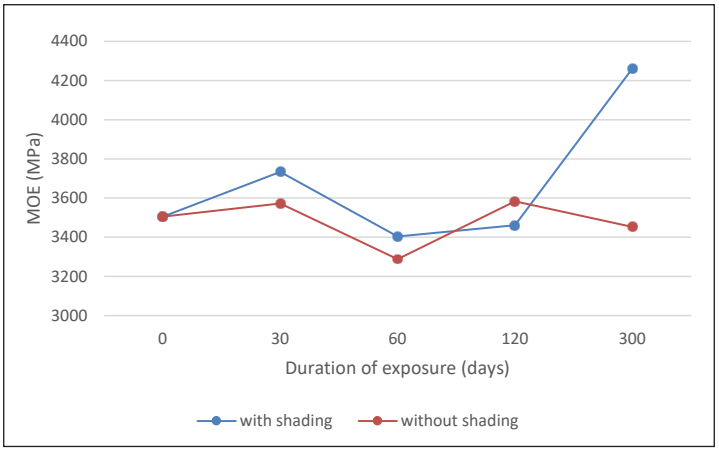

Figure 4. MOE of LL-CBP exposed to external conditions with and without shading for up to 300 days of exposure

Nevertheless, the CBP eventually reached a constant MOE value after 300 days of exposure. On the other hand, for boards exposed to external conditions without shading, the MOE values showed significant differences over the duration of exposure. The maximum MOE value exceeded the Malaysian Standard requirement after 120 days of exposure, representing an increase of approximately 19.5%. Importantly, the MOE mean values remained above the minimum requirement specified by the Malaysian Standard (3000 MPa) throughout the entire exposure period. These results indicate that the LL CBP specimens possess resistance to weathering exposure in the Malaysian climate.

The exposure conditions significantly affect the MOE strength properties of LL CBP, as presented in Table 3. CBP exposed that those with shading recorded higher MOE values than those without shading. The deterioration in MOE for the unshaded exposure may be attributed to the higher temperature, wetting, and humidity in Malaysia's climate. These environmental conditions can significantly impact the physical and mechanical properties of CBP materials. Studies, such as those conducted by Liu et al. (2024), have shown that alkaline wood fibres can degrade the cement matrix, a process exacerbated by moisture, thereby accelerating these processes. This interaction can compromise the stiffness and structural integrity of CBP, as evidenced by reduced MOE values. Further, the cyclic nature of wetting and drying, combined with high temperatures, leads to repeated expansion and contraction of the CBP, resulting in micro-cracking and weakening of the cement-wood bond. This phenomenon has been documented by Yu et al. (2016) and Yilmaz et al. (2015), who note that wood-cement composites, such as LL-CBP, exposed to environmental heat will experience a decline in properties over time. However, the research results for both shaded and unshaded specimens still exceeded the required minimum standard of 3,000 MPa under MS 544.

Effect of Duration Exposure on IB

The effect of duration exposures on IB of LL CBP is provided in Tables 1 and 2. The tables indicated that the mean IB attained was significantly lower compared to that of commercial CBP. The DMRT also indicates that the interaction between IB and duration was highly significant at a 5% significance level. Figure 5 shows a significant decrease in IB of up to 13.7% relative to the initial IB during the first 60 days of exposure under shading conditions. The IB value decreased continuously to 0.75 MPa (21%) relative to the initial IB after 120 days of the exposure test. Additionally, the same trend was observed for specimens exposed to external conditions without shading. The IB value decreased after exposure, and the drop was significantly greater than in those exposed to shading conditions. The IB value gradually decreased to 0.54 MPa, or about 43% of the initial IB, within 120 days of exposure. This may be due to mechanical stress on the binder induced by the particles' swelling forces, which caused poor binding between cement and wood particles under the alternating hot and rainy weather in Malaysia. Furthermore, the stress was probably induced by the tensile force applied to the specimens. According to Melichar et al. (2022) and Pakhomova et al. (2023), the cyclic occurrence of rain and hot weather can induce stress and movement between wood particles and cement. This phenomenon involves alternating tensile and compressive forces in the cement paste and wood particles, potentially compromising the wood particles' effectiveness as reinforcing materials and, consequently, affecting the long-term durability of the composite. Nevertheless, the IB of the LL CBP remained higher than or equivalent to the MS standard requirement of 0.5 MPa for IB after exposure to both environments for up to 300 days.

Table 3 indicates the significant effect of exposure conditions on the IB property of LL CBP. CBP exposed without shading had lower IB values compared to those exposed with

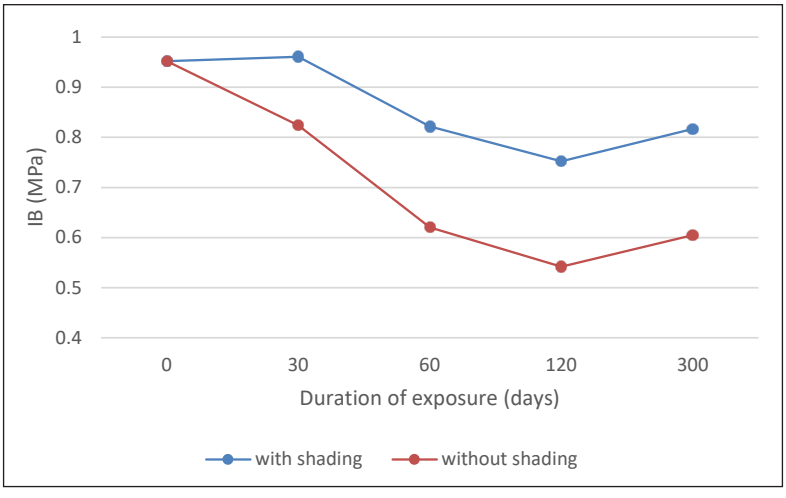

Figure 5. IB of LL CBP exposed to external conditions with and without shading for up to 300 days of exposure

shading. This indicates that weathering substantially impacts the bonding between cement and wood particles. Malaysia's extremely hot and humid climate may cause mechanical stress on the binder, leading to poor binding and reduced strength over time. However, even after 300 days of exposure, the IB values remained above the required MS 544 standard of 0.5 MPa under both shaded and unshaded conditions.

Stereo Compound Microscope Analysis

The effect of A: a microstructural study was used to corroborate the physical characteristics of CBP specimens. The surface morphology of the CBP specimens subjected to external exposure, with and without shading, was evaluated using a stereo compound microscope. The effects of external exposure with and without shading conditions on the LL CBP specimens' physical appearances are exhibited in Figure 6b, Figure 6d, and Figure 6f. The figures illustrate that the CBP specimens underwent morphological changes during and after exposure, particularly under external shading conditions. Hence, the most common degradation phenomenon is the self-debonding of the cement matrix and wood particles at the top surface of the boards, which had been exposed to external conditions without shading. This is probably due to the loss of cement grains from the surface caused by the alternating expansion and contraction of the cement matrix during exposure. Close observation of the board surface with a stereo compound microscope revealed distinct morphologies on the surfaces of CBP specimens exposed to the two conditions. Moreover, the roughening of the external surface without shading was probably due to the loss of cement from the board surface after prolonged exposure to alternating rain, heat, and wind.

For the CBP specimens exposed to shading conditions (Figure 6a, Figure 6c, and Figure 6e) There was a very minimal physical change on the surface and cross-section compared to those exposed without shading conditions. The specimens exposed to this condition always remained dry and grey in colour (the colour of cement). However, a similar CBP exposed to external conditions without shading was noticed to be faded. It is probably due to excessive alternate wetting and drying (Figure 6b) during rain and sunshine. Another common feature is fungal attack. Normally, a fungal attack can be observed with a microscope or by manual inspection. However, after 300 days of exposure, it was discovered that the fungus failed to attack the LL CBP specimens. This was mainly due to the high alkalinity of the CBP specimens (pH of 11.13 to 11.38), a major drawback for fungal development. Therefore, determining the CBP pH is important, as it may influence fungal attack and finishing characteristics of the CBP. In this study, the pH of CBP was tested using a pH meter.

In an earlier study, Kartal et al. (2001) confirmed that the high alkalinity (pH 11.3) and sodium silicate admixture in the CBP mixture were a major factor in improving resistance against insect and fungal attacks. The microphotograph from the stereomicroscope also suggests a dual mechanism of fibre fracture and fibre pullout failure in the LL

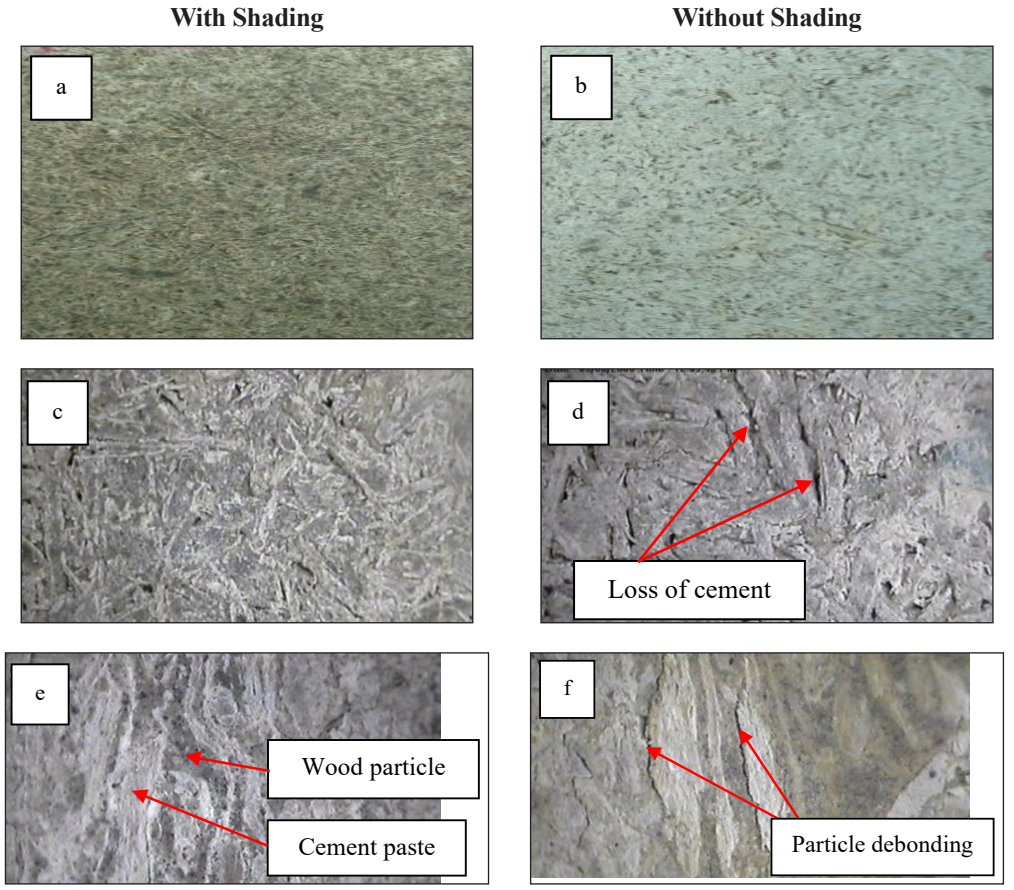

Figure 6. Detailed surface morphology observations on CBP samples exposed to both shaded and unshaded conditions. The top surface of samples a, b, c, and d is a cross-section of the samples, while e and f were examined at a 2× magnification level

CBP specimen (shaded), subjected to a mechanical properties test. It is observed that the test CBP specimens failed due to both failures of the fibre-to-fibre bond (fibre fracture) and fibre-to-cement matrix (fibre pullout) bond, as displayed in Figure 7 and Figure 8. At lower cement percentages, the failure mechanism was primarily attributed to fibre pullout, while at higher cement percentages, fibre fracture became the predominant cause of failure. Furthermore,



Figure 7. A close observation of CBP specimens demonstrating fibre fracture and fibre pullout after being subjected to a bending strength test (magnification 4.5×)

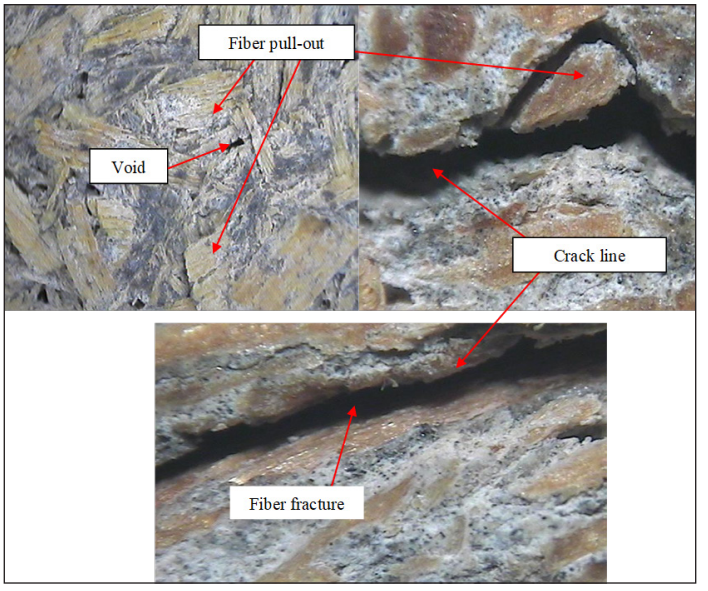

Figure 8. Typical surface of fibre fracture and fibre pullout failure for CBP specimen under IB test (magnification 4.5×)

a detailed analysis of the test specimens' surfaces unequivocally reveals that fibre pullout was the primary fracture failure mode, as depicted in Figure 7. Thus, the microphotograph provides a valuable visual confirmation of various mechanisms present in CBP materials.

CONCLUSION

This study highlights the potential of utilising the fast-growing species LL as an alternative particle source in CBP manufacturing. The results demonstrate that incorporating LL into CBP improved weather resistance under natural Malaysian conditions for up to 300 days. LL CBP showed a significant increase in MOR and MOE after prolonged exposure, particularly under shaded conditions, where it exhibited minimal physical deterioration and superior resistance to environmental stresses compared to unshaded conditions. The findings suggest that LL CBP, despite the challenges posed by high temperatures and moisture in unshaded environments, maintains its structural integrity and performance, attributed to the continuous hydration and hardening of the cement matrix. However, to comprehensively understand the impact of exposure duration on mechanical and physical properties, further research is recommended as follows:

1. Adhesive Optimisation: Optimise the adhesive formulations used in CBP manufacturing with LL particles. Different adhesives may influence the bonding strength and overall performance of the CBP. Hence, finding the most suitable adhesive for this specific material is essential.

2. Finite Element Analysis (FEA): Utilise FEA simulations to model the behaviour of LL-based CBP under different loading scenarios. FEA can provide valuable insights into stress distribution, failure mechanisms, and deformation patterns, optimising material design and engineering.
3. Cost Analysis: Perform a comprehensive cost analysis to assess the economic feasibility of using LL CBP compared to conventional particleboard materials. Understanding the production costs and market competitiveness will facilitate its integration into the industry.

ACKNOWLEDGEMENT

This research was supported by the College of Engineering, UiTM Cawangan Pahang, Malaysia, as well as the services and facilities provided by UiTM Cawangan Pahang to carry out the laboratory work.

REFERENCES

Alexander, M. G., Bentur, A., & Mindess, S. (2017). *Durability of concrete: Design and construction*. CRC Press. https://doi.org/10.1201/9781315118413

Iraldo, F., Facheris, C., & Nucci, B. (2017). Is product durability better for environment and for economic efficiency? A comparative assessment applying LCA and LCC to two energy-intensive products. *Journal of Cleaner Production, 140*, 1353-1364. https://doi.org/10.1016/j.jclepro.2016.10.017

Kartal, S. N., & Clausen, C. A. (2001). Leachability and decay resistance of particleboard made from acid extracted and bioremediated CCA-treated wood. *International Biodeterioration & Biodegradation, 47*(3), 183-191. https://doi.org/10.1016/S0964-8305(01)00047-6

Liu, J., Li, Y., Jin, C., Lin, H., & Yang, B. (2024). Exploring the influence and mechanisms of functionalized nanoscale wood fibre on the electromagnetic transmission performance of OPC paste. *Construction and Building Materials, 420*, Article 135621. https://doi.org/10.1016/j.conbuildmat.2024.135621

Mead, D. J. (2005). Forests for energy and the role of planted trees. *Critical Reviews in Plant Sciences, 24*(5-6), 407-421. https://doi.org/10.1080/07352680500316391

Melichar, T., Bydžovský, J., Brožovský, J., & Vacula, M. (2022). Structural, physical and mechanical changes of cement-bonded particleboards during sudden fluctuations in temperature and moisture. *Journal of Wood Science, 68*, Article 3. https://doi.org/10.1186/s10086-021-02004-3

Mussi Alencar, J. B., & de Melo Moura, J. D. (2019). Mechanical behaviour of cross-laminated timber panels made of low-added-value timber. *Forest Products Journal, 69*(3), 177-184. https://doi.org/10.13073/FPJ-D-18-00037

Nazerian, M., Gozali, E., & Ghalehno, M. D. (2011). The influence of wood extractives and additives on the hydration kinetics of cement paste and cement-bonded particleboard. *Journal of Applied Sciences, 11*(12), 2186-2192. https://doi.org/10.3923/jas.2011.2186.2192

Obiakara, M. C., Olubode, O. S., & Chukwuka, K. S. (2023). Climate change and the potential distribution of the invasive shrub, *Leucaena leucocephala* (Lam.) De Wit in Africa. *Tropical Ecology, 64*(4), 698-711. https://doi.org/10.1007/s42965-023-00294-w

Pakhomova, E., Emelyanov, S., Yartsev, V., Danilov, V., & Monastyrev, P. (2023). The influence of climatic ageing on the performance of wood-based panels. *Civil Engineering Journal, 9*(6), 1491-1508. https://doi.org/10.28991/CEJ-2023-09-06-015

Ramage, M. H., Burridge, H., Busse-Wicher, M., Fereday, G., Reynolds, T. P. S., Shah, D. U., Wu, G., Yu, L., Fleming, P., Densley-Tingley, D., Allwood, J., Dupree, P., Linden, P. F., & Scherman, O. (2017). The wood from the trees: The use of timber in construction. *Renewable and Sustainable Energy Reviews, 68*, 333-359. https://doi.org/10.1016/j.rser.2016.09.107

Sam-Brew, S., & Smith, G. D. (2015). Flax and hemp fibre-reinforced particleboard. *Industrial Crops and Products, 77*, 940-948. https://doi.org/10.1016/j.indcrop.2015.09.079

Simatupang, M. H., & Neubauer, A. (1993). Manufacture and properties of rapid-hardening cement-bonded particleboards made by carbon-dioxide injection: Influence of cement strength class. *Holz als Roh- und Werkstoff, 51*(5), 309-311. https://doi.org/10.1007/BF02663800

Singh, P., Tewari, A., & Pandey, V. (2022). Changes in growth pattern and rhizospheric soil biochemical properties of a leguminous tree species *Leucaena leucocephala* under long-term exposure to elevated ozone. *3 Biotech, 12*(7), Article 152. https://doi.org/10.1007/s13205-022-03215-1

Sudarmanto, Juwono, A. L., Subyakto, Budiman, I., Lubis, M. A. R., Kusumah, S. S., Kusumaningrum, W. B., & Adi, D. S. (2022). Effect of cold-water treatment and hydrothermal carbonization of oil-palm-trunk fibres on compatibility with cement for the preparation of cement-bonded particleboard. *Wood Material Science & Engineering, 17*(6), 979-988. https://doi.org/10.1080/17480272.2021.1983871

Wei, J., & Meyer, C. (2015). Degradation mechanisms of natural fibre in the matrix of cement composites. *Cement and Concrete Research, 73*, 1-16. https://doi.org/10.1016/j.cemconres.2015.02.019

Wiejak, A., & Francke, B. (2021). Testing and assessing method for the resistance of wood-plastic composites to the action of destroying fungi. *Materials, 14*(3), Article 697. https://doi.org/10.3390/ma14030697

Xie, W., Guo, S., Liu, Y., Chen, R., & Wang, Q. (2020). Organic-inorganic hybrid strategy based on ternary copolymerization to prepare flame retardant poly(methyl methacrylate) with high performance. *Composites Part B: Engineering, 203*, Article 108437. https://doi.org/10.1016/j.compositesb.2020.108437

Yilmaz, M., Tokyay, M., & Yaman, I. O. (2016). Cement production by cement-bonded wood particleboard wastes. *Advances in Cement Research, 28*(4), 233-240. https://doi.org/10.1680/jadcr.15.00023

Yu, Y., Hou, J., Dong, Z., Wang, C., Lu, F., & Song, P. (2016). Evaluating the flammability performance of Portland cement-bonded particleboards with different cement-wood ratios using a cone calorimeter. *Journal of Fire Sciences, 34*(3), 199-211. https://doi.org/10.1177/0734904116630758