Impact of nipah palm stem fiber volume fraction on the physical and mechanical properties of cement-based particle board composites

Teguh Prasetyo[1], *Mirza* Pramudia[1*], *Mahrus* Khoirul Umami[1], and *Maga* Herdinan[1]

[1]Department of Industrial and Mechanical Engineering, University of Trunodjoyo Madura, Indonesia.

Abstract. Cement particle boards are highly valued in the construction industry for their excellent physical and mechanical properties. This study investigates the incorporation of nipah palm stem fibers and mussel shell powder as sustainable alternatives to traditional materials in cement particle boards. Innovations in composite materials, such as incorporating natural fibers like nipah palm stem fibers and mussel shell powder, further enhance their environmental sustainability. This study explores improving the mechanical and physical properties of cement particle boards by increasing the volume fraction of nipah palm stem fibers. Nipah palm stem fibers were incorporated at volume fractions of 30%, 40%, and 50%, combined with a fixed 10% mussel shell powder and the remainder as Portland cement. The boards were fabricated using the compression molding method with a 3-ton load and subsequently subjected to physical and mechanical testing. Physical testing revealed a density range of 1.32 to 1.75 g/cm³, moisture content between 8.02% and 9.92%, and water absorption rates from 24.17% to 43.12%, indicating compliance with ISO 8335 and SNI 03-2105-2006 standards. The study concludes that increasing nipah palm stem fiber volume fraction positively influences bending strength, with a maximum strength of 14.71 MPa observed at 50% fiber content, demonstrating the material's potential for structural applications in construction.

1 Introduction

In the development of the modern construction industry, the demand for building materials that are highly durable, economical, and environmentally friendly continues to grow. Conventional materials like wood and bricks often face challenges in terms of resistance to moisture, fire, and pests. This has driven innovation in developing alternative building materials that are superior in physical and environmental characteristics. One solution that has been developed is cement particle board, a composite material product that combines the advantages of natural fibers or particles with the binding and durability of cement [1-3]. Cement particle boards are made from a mixture of organic fibers or aggregates with cement as the binder, which is then processed into solid sheets through compression and drying. This combination produces a material with good mechanical strength, resistance to water, fire, and pests, and is more environmentally friendly because it utilizes existing organic waste [4-5].

Using nipah palm and mussel shells as raw materials for making cement particle boards is one of the innovations in building material development. nipah palm (Nyfa fruticans wurmb) grows in tidal or swampy areas in coastal and mangrove forest regions. The use of nipah fiber and shell fragments in composite materials is for making panels used in eco-friendly construction. Nipah fiber acts as a lightweight yet strong reinforcement, while processed shell fragments can be used as filler or additional reinforcement to enhance the strength and resistance of the composite material against mechanical stress and corrosion. Their combination also improves weather resistance and reduces reliance on synthetic materials. This tree has strong and flexible stem fibers that contain lignocellulose fibers, which have the potential to be used as alternative materials in the cement particle board industry [6-8]. Nipah stem fibers have good tensile strength, flexibility, and high durability while using mussel shells in cement particle boards functions as a filler in the particle board mixture. Mussel shells contain calcium carbonate ($CaCO_3$), which can help increase the density and stability of the particle board. The calcium carbonate composition from mussel shells enhances compressive and tensile strength, improves load-bearing capacity, and reduces the water absorption of the board, making the material more moisture-resistant, and the natural hardness and durability of the mussel shell contribute to the longevity of the composite particle board. Boards reinforced with mussel shells are more resistant to wear and damage over time [9-11].

The performance of composite materials is greatly influenced by several factors, including the volume fraction ratio between the reinforcing component (filler) and the binding element (matrix). This volume fraction ratio plays a crucial role in determining the composite's mechanical, physical, and overall performance

* Corresponding author: pramudiamirza@trunojoyo.ac.id

properties. The volume fraction of a composite is the ratio of the volume of the reinforcing material (such as fibers) to the total volume of the composite, including the matrix (such as plastic resin). The volume fraction in composite materials affects their mechanical and functional properties. Higher volume fractions of reinforcing materials (like fibers) result in higher mechanical strength, such as tensile and bending strength. However, excessively high volume fractions can cause issues like void formation or fiber agglomeration, weakening the structure. On the other hand, low volume fractions reduce the composite's reinforcement capability, making it more brittle and less resistant to mechanical stress. [12,13]. The volume fraction ratio in cement particle boards made from nipah palm stem fibers and mussel shells plays an important role in determining the properties and performance of the composite. This volume fraction refers to the percentage volume of each component (nipah palm stem fibers, mussel shells, cement, and water) within the total volume of the particle board. The arrangement of these proportions is critical because each material has different characteristics that impact the performance strength of the cement particle board. In this study, variations in the composition of nipah palm stem fibers and mussel shells as fillers were carried out to find the optimal mixture of these two components to achieve the best physical and mechanical strength of the cement particle board. A higher volume fraction of nipah palm stem fibers will result in a lighter board. This is because the more significant the proportion of nipah palm stem fibers, the less material with higher density (mussel shell powder and cement) is used, thus reducing the overall mass of the board [14,15].

This study aims to investigate the effect of the volume fraction of the mixture of nipah palm stem fibers and mussel shells on the physical properties and bending strength of cement particle board material produced through the compression molding process.

2 Research methodology

2.1 Preparation of materials

The process of making mussel shell powder begins with soaking the shells for six hours, followed by washing them until the surface is free of any dirt. After the shells are clean, the next step is drying, which is done by exposing them to direct sunlight. The dried shells are soaked in a 5% NaOH alkalization solution for 2 hours, then rinsed and cleaned with water to remove organic contaminants, such as dirt or proteins attached to the shell's surface. Additionally, alkalization helps open the microscopic structure of the shells, enhancing the bonding and adhesion of the fibers, while also reducing fat or oil content. This process can also improve the mechanical properties of the mussel shells, making them more effective as reinforcement materials in composites. The mussel shells that have undergone alkalization are then dried using sunlight for 3 days to remove the moisture content in the shells. The next step is grinding the shells to crush them into powder. The ground shells are then sieved using a 100-mesh sieve. Preparing nipah palm stem fibers begins by crushing the stems or fronds of the nipah palm using a hammer to separate the fibers from the outer bark. After separating the fibers, the next step is soaking them in pure water for 7 days to remove any impurities attached to them. The fibers are then dried by sun exposure for 4 days. The dried fibers are then treated with 5% NaOH for 2 hours, followed by cleaning with pure water. The alkali-treated fibers are dried again, then ground and sieved to a 40-mesh size.

2.2 Manufacturing of cement particle board

Cement particle boards are made from a mixture ratio of nipah palm stem fibers and mussel shell powder with varying proportions of 30%: 10%, 40%: 10%, and 50%: 10%, with the remainder consisting of 10% Portland cement, $CaCl_2$ catalyst, and water as the solvent. The amount of each raw material used to produce the cement particle board is calculated based on the volume of a 200 x 50 x 10 mm particle board. After the raw materials are evenly mixed, a mat sheet is uniformly formed in a single-layer particle board type mold, followed by pressing under a 3-ton load using a hydraulic press machine. This pressing method is also known as the compression molding method. The result of the compaction process is then dried in open-air conditions for 7 days. The compression molding method is a composite manufacturing technique that involves heating the material and then applying pressure to shape it into the desired form. This process is commonly used in the production of various composite products, including cement particle boards, with the goal of creating a strong and homogeneous structure [16].

2.3 Specimen test

The testing includes physical property tests (density, moisture content, water absorption) and mechanical testing, specifically the modulus of rupture (MOR). Physical property tests utilize tools such as calipers, digital scales, drying ovens, and soaking tanks, while mechanical testing involves bending tests using a Universal Testing Machine (UTM). The calculated values of physical properties and mechanical property tests are then analyzed and compared against the standards for cement particle boards, namely the International standard ISO 8335: 1987, JIS A 5417, and SNI 03-2105-2006.

2.3.1 Density test

Density testing is conducted by measuring the dry weight and then determining the length, width, and thickness of particle boards. The density test follows the SNI 03-2105-2006 standard with a specimen size of 10 x 10 cm. The density test is calculated using the following equation [17]:

$$\rho = \frac{m}{V} \quad (1)$$

Where,
ρ = specimen density (Kg/cm^3)
m = specimen mass (Kg)
V = spesimen volume (cm^3)

2.3.2 Moisture content testing

Moisture content testing is conducted by measuring the initial weight (m_1), then drying the specimen in an oven at a temperature of approximately 100 ± 2°C for 24 hours. Afterward, the specimen is reweighed to determine the dry weight after oven drying (m_2). The moisture content test follows the SNI 03-2105-2006 standard with a specimen size of 10 x 10 cm. This test can be calculated using the following equation [18]:

$$MC\ (\%) = \frac{m_1}{m_2} \times\ 100\ \% \quad (2)$$

Where:
m_1 : Initial weight of the specimen (before drying) in grams.
m_2 : Dry weight of the specimen (after oven drying) in grams.

2.3.3 Water absorption testing

Water absorption testing is performed by immersing the specimen in water for 24 hours. Before immersion, the initial dry weight of the specimen (m_1) is measured. After immersion, the specimen is removed, surface water is wiped off, and the final wet weight (m_2) is recorded. This test follows the SNI 03-2105-2006 standard with a specimen size of 10 x 10 cm. The water absorption value is calculated using the following equation [19]:

$$WA\ (\%) = \frac{m_2 - m_1}{m_1} \times\ 100\ \% \quad (3)$$

Where:
m_1 : Dry weight of the specimen (in grams).
m_2 : Wet weight of the specimen after immersion (in grams).

2.3.4 Modulus of Rupture (MoR)

Modulus of Rupture describes the capacity of a material to absorb elastic energy per unit volume without causing permanent deformation. More specifically, MoR refers to the maximum energy a material can store during its elastic deformation phase before reaching its limit or yield point. This test is performed by applying a load to the specimen at three points: two support points at the bottom and one loading point in the centre. The purpose is to determine the maximum strength of the material before it fractures or cracks. The testing method follows the SNI 03-2105-2006 standard using a Universal Testing Machine (UTM). The test specimen measures 20 cm x 5 cm, with a span length of 15 cm between the supports. The Modulus of Rupture can be calculated using the following formula [20]:

$$MoR = \frac{3FL}{2bh^2} \quad (4)$$

Where:
F = Maximum load applied before failure (in Newtons)
L = Span length between the supports (in meters)
b = Width of the specimen (in meters)
d = Thickness of the specimen (in meters)

3 Results and discussion

3.1 Density test

Density testing was conducted on the cement particle boards to determine the density of each sample of the cement particle boards. The results of the density tests are shown in the following Table 1:

Table 1. Density of cement particle boards made from a mixture of nipah palm stem fibers and mussel shell powder based on variations in volume fraction composition.

No	Specimen	Volume Fraction Variations	Average Density (gr/cm^3)	ISO 8335-1987	JIS A 5417-1992	SNI 03-2105-2006
1	A	30% nipah palm stem fibers : 10% mussel shell powder	1,753	> 1 g/cm^3	> 0,8 g/cm^3	0,4 - 0,9 g/cm^3
2	B	40% nipah palm stem fibers : 10% mussel shell powder	1,441			
3	C	50% nipah palm stem fibers : 10% mussel shell powder	1,322			

Based on the table above, the average density value of the particle board in sample A is 1.753 g/cm³, sample B has an average density of 1.441 g/cm³, and sample C has an average density of 1.322 g/cm³. The data obtained indicate that the density values of all cement particle board samples have met the requirements of ISO 8335-1987, which is more than 1 g/cm³, and JIS A 5417-1992, which is greater than 0.8 g/cm³, but do not meet the SNI 03-2105-2006 standards. The table above shows that the highest density value of the particle board is found in sample A, with a composition of 30% nipah palm stem fibers and 10% shell powder. In contrast, the lowest density is found in sample C, with a composition of 30% nipah palm stem fibers and 10% shell powder. This indicates that the density of the composite board increases with the reduction of the powder content derived from natural fibers and constant cement. The decrease in density corresponds with the increase in

fiber content in the composite due to the relatively lighter nature of the fibers. The less fiber used and the more shell powder used, the higher the density value. x

Conversely, if more fiber is used and less shell powder is used, the density of the cement particle board will decrease. Nipah palm stem fibers is a fibrous material with lower density and a more porous structure. As the volume fraction composition of nipah palm stem fibers increases, there will be more space between particles, leading to increased porosity and reduced material density. The reduction of nipah palm stem fibers results in fewer cavities or empty spaces formed in the particle board. The presence of these voids can be filled by denser materials, such as cement and shell powder, significantly impacting the increase in density values **[21-22]**.

3.2 Moisture content test

Moisture content testing is conducted to determine the moisture content in each sample of cement particle board. The results of the moisture content test on the specimens of cement particle board made from a mixture of nipah palm stem fibers and shell powder are shown in Table 2 below :

Table 2. The moisture content of cement particle board made from a mixture of nipah palm stem fibers and shell powder based on variations in the composition of volume fractions.

No	Specimen	Volume Fraction Variations	Average Moisture Content (%)	ISO 8335 - 1987	JIS A 5417 - 1992	SNI 03-2105 - 2006
1	A	30% nipah palm stem fibers : 10% mussel shell powder	8,02	6-12 %	< 16%	< 14%
2	B	40% nipah palm stem fibers : 10% mussel shell powder	9,45			
3	C	50% nipah palm stem fibers : 10% mussel shell powder	9,92			

Table 2 shows that the average moisture content of the particle board in sample A is 8.02%, sample B has an average moisture content of 9.45%, and sample C has an average moisture content of 9.92%. The data indicate that the moisture content of all particle board samples meets the three standards: ISO 8335-1987, JIS A 5417-1992, and SNI 03-2105-2006. The table reveals that as the volume fraction of Nipah powder increases, the moisture content of the cement particle board material also increases. In the particle board mixture, cement and shell powder have higher densities and tend not to absorb water, unlike the characteristics of Nipah powder. When the proportion of Nipah powder is low, more space is filled by cement and shell powder. These two materials are denser and have a lower capacity to absorb moisture, thereby helping to reduce the total moisture content of the board **[23]**.

3.3 Water absorption test

The water absorption test is conducted on cement particle boards to determine the water absorption capacity of each sample of cement particle board. The results of the water absorption test are shown in Table 3.

Table 3. Water absorption after soaking the cement particle board mixed with nipah powder and clam shell powder based on variations in volume fraction composition.

No	Specimen	Volume Fraction Variations	Average Water Absorption (%)	ISO 8335-1987	JIS A 5417-1992	SNI 03-2105-2006
1	A	30% nipah palm stem fibers : 10% mussel shell powder	25,42	-	-	-
2	B	40% nipah palm stem fibers : 10% mussel shell powder	24,17			
3	C	50% nipah palm stem fibers : 10% mussel shell powder	43,12			

Based on the data above shows a tendency that as the volume fraction of nipah palm stem fiber increases, the water absorption value of the specimens also increases. In the particle board mixture, cement and clamshell powder have a higher density and tend to absorb less water than Nipah powder. When the proportion of Nipah palm stem fiber is low, more space is filled by cement and clamshell powder. These two materials are denser and have a lower ability to absorb moisture, thus helping to reduce the overall moisture content of the cement particle board [24,25].

3.4 Bending strength test (Modulus of rupture)

The bending strength test was conducted on a cement particle board to determine each sample's Modulus of Rupture (MOR) strength. MoR represents the material's ability to withstand bending or tensile loads before fracturing or failing. This test is performed by applying a force to a specimen using a three-point bending test until the specimen breaks.

Table 4. The Modulus of Rupture (MoR) of cement particle board made from a mixture of nipa palm fiber and clam shell powder based on variations in volume fraction.

No	Specimen	Volume Fraction Variations	Average MoR (MPa)	ISO 8335 - 1987	JIS A 5417 - 1992	SNI 03-2105 - 2006
1	A	30% nipah palm stem fibers : 10% mussel shell powder	5,63	> 9 MPa	> 6,2 MPa	> 8,04 MPa
2	B	40% nipah palm stem fibers : 10% mussel shell powder	14,01			
3	C	50% nipah palm stem fibers : 10% mussel shell powder	14,71			

Table 4 above shows that the MoR values of the test materials with a ratio of 40% nipa palm fibers: 10% clam shell powder and 50% nipa palm fibers: 10% clam shell powder meet the requirements of ISO 8335-1987, JIS A 5417-1992, and SNI 03-2105-2006. Meanwhile, the test material with a treatment of 30% nipa palm fibers: 10% clam shell powder does not meet the specified requirements. As the volume fraction of nipa palm fibers increases, the MoR value also increases. This is because nipa palm fibers serve as reinforcements in the cement particle board, helping to strengthen the material by resisting tensile forces during bending loads. When the volume fraction of nipa palm fibers is low, the material loses the function of this reinforcing element, resulting in a decrease in toughness and bending strength of the composite overall. Cement particle boards must comply with ISO 8335-1987, JIS A 5417-1992, and SNI 03-2105-2006 standards to ensure the quality, safety, and durability of the material in various construction applications. These standards define technical specifications, including mechanical strength, moisture resistance, and the material's environmental resilience. Adhering to these standards guarantees product consistency and builds user confidence in the durability and performance of cement particle boards under diverse usage conditions [26,27].

3.5 Microstructure analysis

The aim of the microstructure testing of the fracture pattern on cement particle board is to understand how the material fails or fractures when subjected to mechanical loads, as well as to identify the fracture mechanisms occurring within the cement particle board material. The results of the microstructure testing of the fracture pattern are shown in Figure 1.

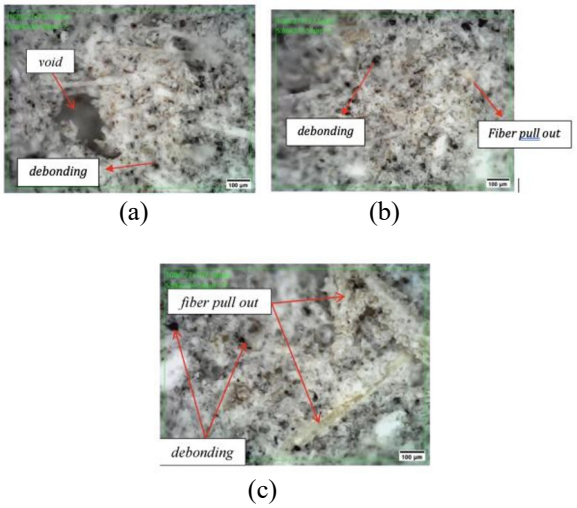

Fig. 1. (a) Microstructure of 30% nipa palm fibers : 10% clam shell powder, (b) Microstructure of 40% nipa palm fibers : 10% clam shell powder, (c) Microstructure of 50% nipa palm fibers : 10% clam shell powder.

The analysis results of the microstructure indicate several phenomena occurring in the fracture pattern of the cement particle board specimens, namely voids, debonding, and fiber pull-out. Voids in the cement particle board are cavities or gaps formed within the material during the manufacturing process, which can be caused by various factors such as incomplete mixing, evaporation of water or trapped air during drying, or insufficient pressure during the formation of the cement particle board. The presence of voids in the cement particle board can negatively impact the mechanical and physical properties of the material. Voids reduce the modulus of rupture of the cement particle board. They create weak points that can initiate cracks when the material is subjected to mechanical loads. The next phenomenon observed is the debonding mechanism, which refers to the failure caused by the separation of bonds between particles in the composite material—in this case, occurring between the nipa palm fibers and the shell powder with the Portland cement binder. Debonding in the cement particle board can weaken the board's structure and reduce its mechanical strength. The analysis of the fracture pattern of the cement particle board also indicates the occurrence of fiber pull-out, which is the failure of the cement particle board when the fibers or filler particles within the board detach from the cement matrix. This represents a failure in the bonding between the nipa palm fibers and the cement matrix, leading to a decrease in the strength and structural integrity of the board [28-30].

4 Conclusion

Based on the results of the physical tests (density, moisture content, and water absorption) as well as the mechanical testing of the cement particle board specimens made from a mixture of nipa palm fibers and clam shell powder, it can be concluded that the density of the test specimens meets the requirements of ISO 8335-1987, which is greater than 1 g/cm³, and JIS A 5417-1992, which is greater than 0.8 g/cm³; however, it does not meet the SNI 03-2105-2006 standard. The moisture content tests indicate that all specimens meet the standards of ISO 8335-1987, JIS A 5417-1992, and SNI 03-2105-2006. Meanwhile, the water absorption tests show that an increase in nipa palm powder volume fraction leads to a higher water absorption value for the specimens. In the mechanical testing, a bending test was conducted to determine each sample's Modulus of Rupture strength. The mechanical testing results demonstrate that the compositions of 40% nipa palm fibers to 10% clam shell powder and 50% nipa palm fibers to 10% clam shell powder meet the requirements of ISO 8335-1987, JIS A 5417-1992, and SNI 03-2105-2006. In contrast, the test material, which had a composition of 30% nipa palm fibers and 10% clam shell powder, did not meet the specified requirements. The analysis of the bending fracture patterns reveals failure mechanisms caused by voids, debonding, and fiber pull-out in the cement particle board specimens.

References

1. L. Chen, L. Wang, D. C. Tsang, V. Mechtcherine, C. S. Poon, Efficacy of green alternatives and carbon dioxide curing in reactive magnesia cement-bonded particleboards. Journal of Cleaner Production. **258**, 120997 (2020). https://doi.org/10.1016/j.jclepro.2020.120997
2. L. Wang, K. M. Iris, D. C. Tsang, K. Yu, S. Li, C. S. Poon, J. G. Dai, Upcycling wood waste into fibre-reinforced magnesium phosphate cement particleboards. Construction and Building Materials. **159**, 54–63 (2018). https://doi.org/10.1016/j.conbuildmat.2017.10.107
3. I. O. Ohijeagbon, A. A. Adeleke, V. T. Mustapha, J. A. Olorunmaiye, I. P. Okokpujie, P. P. Ikubanni, Development and characterization of wood-polypropylene plastic-cement composite board. Case Studies in Construction Materials. **13**, e00365 (2020). https://doi.org/10.1016/j.cscm.2020.e00365
4. M. J. De Souza, R. R. De Melo, J. B. Guimarães Jr, T. K. Carnaval, A. S. Pimenta, A. R. Mascarenhas, Wood-cement boards with addition of coconut husk. Wood Material Science & Engineering. **17**, 6, 617–626 (2022). https://doi.org/10.1080/17480272.2021.1914722
5. O. D. Atoyebi, C. O. Osueke, S. Badiru, A. J. Gana, I. Ikpotokin, M. A. Modupe, G. A. Tegene, Evaluation of particle board from sugarcane bagasse and corn cob. International Journal of Mechanical Engineering and Technology. **10**, 1, 1193–1200 (2019).
6. H. Nurdin, W. Waskito, A. N. Fauza, B. M. Siregar, B. K. Kenzhaliyev, The investigation of physical and mechanical properties of Nipah-based particle board. Teknomekanik. **6**, 2, 94–102 (2023). https://doi.org/10.24036/teknomekanik.v6i2.25972
7. R. S. Ghani, M. S. Osman, A. I. Rani, Exploring the potential of Nipah palm frond as sustainable raw material for eco-friendly particleboard production. Cleaner and Circular Bioeconomy. **100092**, (2024). https://doi.org/10.1016/j.clcb.2024.100092
8. H. Nurdin, M. Saddikin, Characteristics of particleboard from waste Nypa fruticans Wurmb. Journal of Physics: Conference Series. **1387**, 1, 012103 (2019). https://doi.org/10.1088/1742-6596/1387/1/012103
9. C. Martínez-García, B. González-Fonteboa, D. Carro-López, F. Martínez-Abella, J. P. Ordóñez, Characterization of mussel shells as a bio-based building insulation material. Academic Journal of Civil Engineering. **37**, 2, 525–531 (2019)
10. J. N. Murphy, C. M. Schneider, K. Hawboldt, F. M. Kerton, Hard to soft: Biogenic absorbent sponge-like material from waste mussel shells. Matter. **3**, 6, 2029–2041 (2020). https://doi.org/10.1016/j.matt.2020.09.022
11. A. E. Sahin, B. Cetin, T. Sinmazcelik, Effect of mussel shell reinforcement on mechanical and tribological behavior of polyphenylene sulfide composites. Journal of Thermoplastic Composite Materials. **35**, 9, 1279–1302 (2022). https://doi.org/10.1177/0892705720930787
12. A. Hariyanto, A. D. Anggono, D. A. Pratiwi, A. B. Amali, S. Melaty, Z. K. Adi, Ngafwan, Supriyono, U. Kultsum, Effect of volume fraction of epoxy matrix coconut shell composite on tensile and impact loads. Engineering Proceedings. **63**, 1, 14 (2024). https://doi.org/10.3390/engproc2024063014
13. M. Y. Zaghloul, M. M. Zaghloul, M. M. Zaghloul, Influence of stress level and fibre volume fraction on fatigue performance of glass fibre-reinforced polyester composites. Polymers. **14**, 13, 2662 (2022). https://doi.org/10.3390/polym14132662
14. S. Eddy, M. Taufik, A. A. Setiawan, B. Utomo, M. Oktavia, Study of population distribution and benefits of Nipah (Nypa fruticans). E3S Web of Conferences. **475**, 02007 (2024). https://doi.org/10.1051/e3sconf/202447502007
15. A. Hasan, M. S. Rabbi, M. M. Billah, M. A. Hasib, Effect of chemical treatments on properties of injection molded Nypa fruticans fiber reinforced polypropylene composite. Heliyon. **8**, 12, (2022). https://doi.org/10.1016/j.heliyon.2022.e11967
16. J. Jaafar, J. P. Siregar, C. Tezara, M. H. Hamdan, T. Rihayat, A review of important considerations in the compression molding process of short natural fiber composites. The International Journal of Advanced Manufacturing Technology. **105**, 3437–

3450 (2019). https://doi.org/10.1007/s00170-019-04466-8

17. A. A. Adediran, O. A. Balogun, A. A. Akinwande, O. S. Adesina, O. S. Olasoju, Influence of chemical treatment on the properties of cement-paper hybrid composites for ceiling board application. Heliyon. **6**, 7, (2020). https://doi.org/10.1016/j.heliyon.2020.e04512
18. S. O. Odeyemi, R. Abdulwahab, A. G. Adeniyi, O. D. Atoyebi, Physical and mechanical properties of cement-bonded particle board produced from African balsam tree and periwinkle shell residues. Results in Engineering. **6**, 100126 (2020). https://doi.org/10.1016/j.rineng.2020.100126
19. H. Yel, A. D. Cavdar, S. B. Torun, Effect of press temperature on some properties of cement bonded particleboard. Maderas. Ciencia y Tecnología. **22**, 1, 83–92 (2020). https://doi.org/10.4067/S0718-221X2020005000108
20. V. A. Vu, A. Cloutier, B. Bissonnette, P. Blanchet, J. Duchesne, The effect of wood ash as a partial cement replacement material for making wood-cement panels. Materials. **12**, 17, 2766 (2019). https://doi.org/10.3390/ma12172766
21. W. Maynet, E. M. Samsudin, N. N. Soh, Physical and mechanical properties of cement board made from oil palm empty fruit bunch fibre: A review. IOP Conference Series: Materials Science and Engineering. **1144**, 1, 012008 (2021). https://doi.org/10.1088/1757-899X/1144/1/012008
22. T. Melichar, L. Meszarosova, J. Bydzovsky, M. Ledl, S. Vasas, The effect of moisture on the properties of cement-bonded particleboards made with non-traditional raw materials. Journal of Wood Science. **67**, 1–8 (2021). https://doi.org/10.1186/s10086-021-02008-z
23. L. Nunes, E. Cintura, J. L. Parracha, B. Fernandes, V. Silva, P. Faria, Cement-bonded particleboards with banana pseudostem waste: Physical performance and bio-susceptibility. Infrastructures. **6**, 6, 86 (2021). https://doi.org/10.3390/infrastructures6060086
24. A. D. Cavdar, H. Yel, S. B. Torun, Microcrystalline cellulose addition effects on the properties of wood cement boards. Journal of Building Engineering. **48**, 103975 (2022). https://doi.org/10.1016/j.jobe.2021.103975
25. P. He, M. U. Hossain, C. S. Poon, D. C. Tsang, Mechanical, durability and environmental aspects of magnesium oxychloride cement boards incorporating waste wood. Journal of Cleaner Production. **207**, 391–399 (2019). https://doi.org/10.1016/j.jclepro.2018.10.015
26. W. Maynet, E. M. Samsudin, N. N. Soh, Physical and mechanical properties of cement board made from oil palm empty fruit bunch fibre: A review. IOP Conference Series: Materials Science and Engineering. **1144**, 1, 012008 (2021). https://doi.org/10.1088/1757-899X/1144/1/012008
27. R. C. Oliveira, R. A. Bispo, M. F. Trevisan, C. G. Gilio, F. R. Rodrigues, S. A. Silva, Influence of leather fiber on modulus of elasticity in bending test and of bend strength of particleboards. Materials Research. **24**, e20210287 (2021). https://doi.org/10.1590/1980-5373-mr-2021-0287
28. M. Martijanti, S. Sutarno, A. L. Juwono, Polymer composite fabrication reinforced with bamboo fiber for particle board product raw material application. Polymers. **13**, 24, 4377 (2021). https://doi.org/10.3390/polym13244377
29. A. Bartos, J. Kócs, J. Anggono, J. Móczó, B. Pukánszky, Effect of fiber attrition, particle characteristics and interfacial adhesion on the properties of PP/sugarcane bagasse fiber composites. Polymer Testing. **98**, 107189 (2021). https://doi.org/10.1016/j.polymertesting.2021.107189
30. M. A. Karim, M. M. Shah, M. F. Jundam, S. Abdullah, Investigation of tensile properties of the eco-board of hybrid composite that consist of oil palm empty fruit bunch fiber added with rice husk. IOP Conference Series: Materials Science and Engineering. **834**, 1, 012012 (2020). https://doi.org/10.1088/1757-899X/834/1/012012