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Effects of Fibre Length on the Physical Properties of Oil Palm Empty Fruit Bunch Cement Board (OPEFB-CB)

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ABSTRACT

In a cement board (CB) composite, fibres reinforce the board. It is because the length of the fibres significantly impacts the strength of the CB composite. Nonetheless, the physical properties of the CB are also an important aspect when dealing with the quality control of the final product. This study investigates the effects of various fibre lengths in CB fabrication on its physical properties, including the cement-hydration rate, tensile strength, density stability and thickness swelling (TS). Oil palm empty fruit bunch (OPEFB) fibres at different lengths are used based on the mesh retained size of R7M, R14M, and R30M. The OPEFB-CB mixture used in this research is 3:1 (cement: fibre ratio), with a target density of 1,300 kg/m^3. The sample is compressed using a 1000 psi cold-compression load to achieve the desired composite thickness of 12 mm. This research revealed that the longest fibres retained on the R7M mesh with an average length of 5 mm resulted in lower density and the highest TS value. Meanwhile, lower dimensional stability was achieved by OPEFB-CB composites using fibre that retained on the R14M and R30M, having an average length of 3 mm and 1 mm, respectively. Based on the results, the optimum fibre length recommended in the fabrication of OPEFB-CB composites is processed fibres retained on the R14M sieve with an average length of 3 mm. This recommendation is made based on the most stable density and lowest TS results achieved by the R14M retained fibres which is in the range of 1,231–1,309.4 kg/m^3 and TS of 0.65 %.

Keywords: Density, fibre length, hydration rate, OPEFB-CB, ratio, tensile strength, thickness swelling

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INTRODUCTION

Recently, research and development of eco-friendly or green construction materials have been gaining interest among researchers. Recycling waste materials, especially from agricultural activities, into building components is one of the most popular eco-friendly approaches among researchers. The use of wood as natural reinforcement in cement boards (CB) has increased rapidly due to the high demand of construction industries (Kochova et al., 2015). Cement boards are building and construction materials mostly applied in roofing and/or facades due to their strength and durability. They are made up of primarily cement-bonded particle boards and cement-fibre boards, usually applied as roofs and other high-security building elements. Several factors affect the performance of the physical properties of CB, for example, various lengths of the fibre (Akasah et al., 2019). Research conducted by Sugiman et al. (2019) found that the fibre length influenced the workability and increasing impact strength of cement board. Heterogeneous fibre length can improve various mechanical properties of CB as compared to only one larger fibre size. Most outcomes have agreed that reinforced natural fibre has a better-performing load transfer mechanism and results in higher mechanical properties (Jeyapragash et al., 2020). The empty fruit bunch fibre was selected as an economical and sustainable natural fibre compared to others and has shown comparable quality to high-strength kenaf bast fibres (Ayu et al., 2020).

Numerous studies on the subject have been done and are being examined. Flexible board panels or loose-fill insulation in structures can be insulated with insulation fibre manufactured from EFB. With other materials like kenaf, coconut fibre, or hemp, the lambda value is thus fairly comparable. The material is not as widely accessible as EFB fibre and is quite pricey. The insulation also benefits from applying to roof insulation systems (Kaliwon et al., 2012).

However, research using various lengths of oil palm empty fruit bunch (OPEFB) fibres in producing empty fruit bunch-cement board (OPEFB-CB) is still lacking. Therefore, this research analysed and determined the appropriate fibre length used in the fabrication of OPEFB-CB composite with a constant mix design of 3:1 and density of 13000 kg/m^3 that is able to give significant impact to EFBCB contributes to a good performance of OPEFB-CB.

MATERIALS AND METHODS

This research used EFB fibres obtained from a local palm oil processing mill. The EFB was processed in the laboratory and used to fabricate the CB panel size of 350 mm × 350 mm × 12 mm (thickness). This study comprised three stages of laboratory work. The first stage is OPEFB fibre preparation, which involves the pre-treatment of fibre using sodium hydroxide (NaOH). The next stage was stage 2, the fabrication process. The mixture of cement, water, and fibre was prepared according to a ratio of 3:1, followed by the moulding and cutting of the OPEFB-CB samples for testing. Stage 3, the OPEFB-CB underwent physical and mechanical properties tests (hydration rate, tensile strength, density, and thickness swelling).

Fibre Preparation

The OPEFB fibres were collected from Ban Dung Palm Oil Industries Sdn. Bhd. in Parit Sulong, Batu Pahat, Johor. Loose OPEFB fibres were sun-dried for two days to remove the excessive moisture. The sun-dried fibres were hammer-milled and filtered using sieves according to different fibre lengths. The fibre length consisted of three passing mesh sizes (R7M, R14M, and R30M), as classified in Table 1. During this process, all sieves were placed on the top of the vibrating table and vibrated for 1–2 minutes. This process separates most of the fibres' dust while retaining some shorter fibres in the sieves.

Table 1
OPEFB fibre lengths based on the mesh sizes

OPEFB Fibre Length (mm)		
Passing 4 mesh, Retained 7 mesh (R7M)	**Passing 7 mesh, Retained 14 mesh (R14M)**	Passing 14 mesh, Retained 30 mesh (R30M)
5 mm	3 mm	1 mm

According to Ibrahim et al. (2015), pre-treatment is needed to remove contaminants from the fibre surface and lignin, wax, and oil, which might affect cement hydration. Many studies recommended using sodium hydroxide (NaOH) in the pre-treatment of EFB (Izani et al., 2013; Akasah et al., 2019). As Izani et al. (2013) mentioned, the most effective amount of NaOH for EFB treatment is soaking in a 2% NaOH solution for 30 min. Meanwhile, Elkordi (2014) preferred a 4% NaOH concentration for 24 h to pre-treatment fan palm fibres. Fewer studies have attempted using a very low NaOH concentration in the fibre pre-treatment, except for Ibrahim et al. (2015), which applied various concentrations below 1%. Their research used 0.2%, 0.4%, 0.6%, and 0.8% of NaOH in the pre-treatment but with the addition of acetic acid into the solutions. OPEFB fibre was soaked in this research with 0.4 % NaOH concentration for 24 hours. After being soaked for 24 hours, fibres were rinsed thoroughly to remove the remaining alkali content due to the pre-treatment process. Next, the washed fibres were sun-dried to remove excess moisture and dried using a controlled oven-dry at 100°C for 24 hours. The oven-dry method allowed the moisture content of the fibre to be controlled at approximately ±5 %.

OPEFB Cement Board Fabrication

The size of the OPEFB-CB sample fabricated in this research is 350 mm × 350 mm × 12 mm with a targeted density of 1,300 kg/m^3. The fabrication of OPEFB-CB composites used a mixture of Portland cement, water, and EFB fibre, as shown in Figure 1. Fibre, water, and cement were mixed in a mixer for 8–10 min at 60–80 rpm, whereas the hand-forming method was used to fill the mixture into the mould. After that, the mixture was hand-pressed using a plywood plate. A polythene sheet was placed on top of the mixture, followed by a steel plate prior to the machine-pressing procedure. Next, the OPEFB-CB mixture was set for final pressing within 5–7 minutes at an applied pressure of 1000 psi at an 18 mm/min rate using a hydraulic cold-press machine until the thickness reached 12 mm. The pressed sample is tightly clamped before the load is released, and the sample is removed from the machine. The sample was de-clamped after 24 hours and stacked vertically for 28 days for the air-curing process at room temperature (Onuorah et al., 2016). The fabrication process of the OPEFB-CB composite is illustrated in Figure 2.

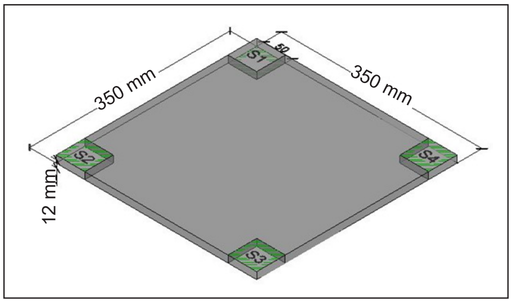


Figure 1. OPEFB-CB test sample based on different locations

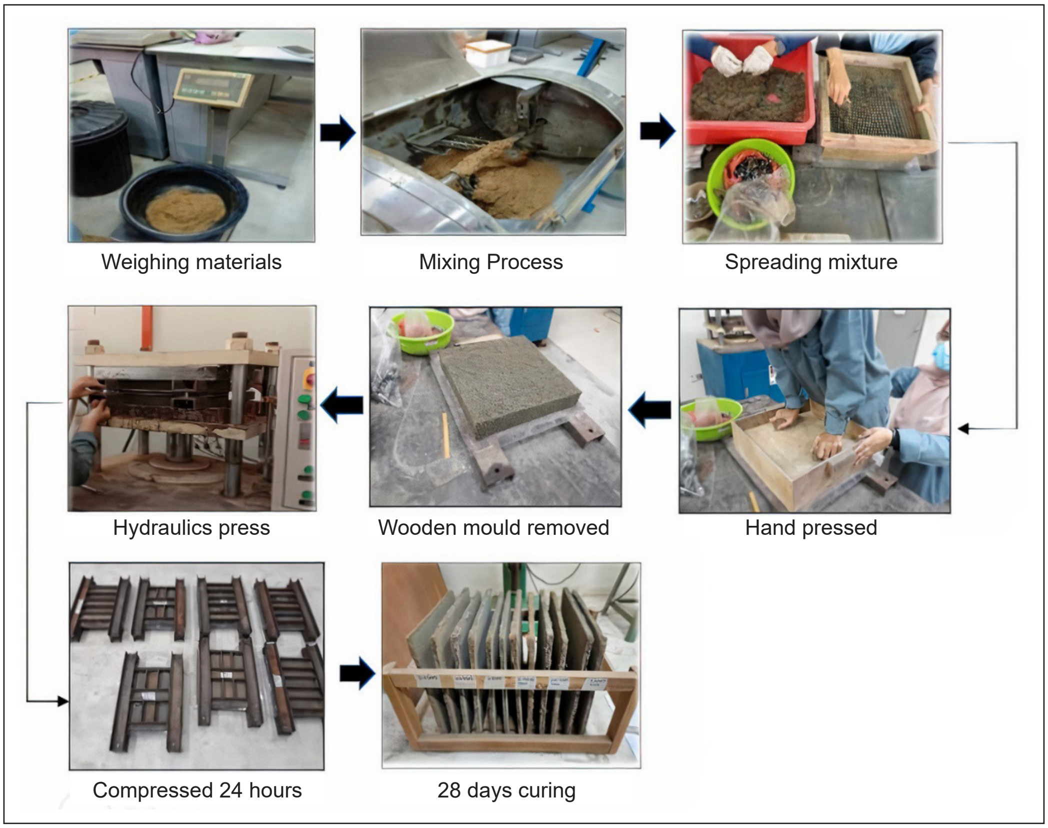


Figure 2. Fabrication process of OPEFB-CB composites

Physical Properties Testing

In this research, the physical properties determined were the selection criteria of OPEFB fibre pre-treatment using sodium hydroxide, hydration rate, tensile strength, density and thickness swelling. The physical properties of OPEFB-CB composites were analysed and discussed based on different fibre lengths of 5 mm for R7M, 3 mm for R14M, and 1 mm for R30M.

The selection criteria of sodium hydroxide (NaOH) for pre-treatment are based on the untreated fibre of 0% and treated fibre of 0.4%. Pre-treatment on OPEFB fibre significantly removes a certain amount of silica bodies that can potentially increase the fibre's workability. At the same time, untreated (UT) fibre has excess impurities and oil content and can reduce the compatibility between fibre and cement, thereby reducing the strength of the fibre. Natural fibre-to-cement compatibility is a main problem in OPEFB-CB production. Adding a certain amount of natural fibre into cement composites significantly reduces the hydration temperature of the mixture. This research also observed the hydration rates of neat cement and cement with OPEFB fibre within 24 hours for both UT and treated fibres. Data were recorded to observe the temperature changes and compared between the neat cement with the mixed material based on the treatment.

The chemical composition of EFB fibres includes lignin, hemicellulose, and cellulose. Cellulose is a significant strength and stability component (Supranto et al., 2014). Higher cellulose content can be obtained by increasing the solutions in NaOH concentrations during pre-treatment. However, increasing the NaOH concentration caused the hemicellulose and lignin in EFB fibre to decrease much more than cellulose, as Aanifah et al. (2014) observed. Cellulose is the main structural component of the strand cell walls. As a result, the lower cellulose content of untreated EFB fibre explicates its low tensile strength. Furthermore, when NaOH pre-treatment was used, the cellulose content showed a better effect on the strength of EFB fibre.

The density of OPEFB-CB composites was determined using a weighing balance by determining the weight of the sample after the curing period. The parameter measurement result was examined based on an average of four locations on the CB, labelled S1, S2, 23, and S4, as shown in Figure 4. The TS experimental test measured the water absorption of OPEFB-CB composites after 28 days of curing. The test procedure follows the British Standard requirement below 1.5%. The dimension of the test piece was 50 mm × 50 mm × 12 mm. The samples were immersed in water for 24 h at room temperature. The thickness of the sample (t_1) was recorded on every four sides of the sample, as shown in Figure 4. The thickness after immersion (t_2) was also recorded, and the average of each side of the sample was calculated. The thickness increases as the sample absorb water. The TS was calculated using Equation 1 based on the difference in thickness:

$$\text{TS } (\%) = \frac{t2-t1}{t1} \times 100\% \qquad [1]$$

This study used the hand-forming method for OPEFB-CB fabrication based on different lengths and a fixed mixing ratio of 3:1. Figure 1 shows the selection of sample area for the density test of the OPEFB-CB composites based on different locations.

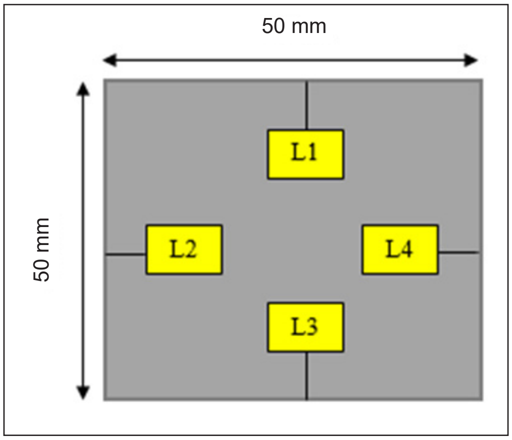


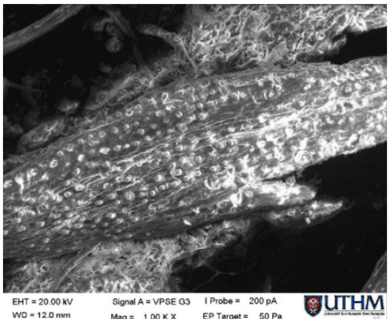
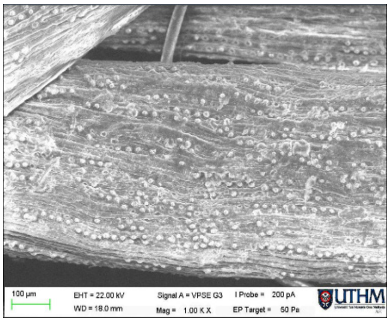
Figure 3. OPEFB-CB test sample (50 mm × 50 mm) based on four sides

This method is based on four locations for the OPEFB-CB samples presented in Figure 3. Its purpose is to identify the consistency of the density distribution of the cement-fibre mixture for the OPEFB-CB samples. The density values at each location were recorded and analysed through the plotted graph. The results determine if the OPEFB-CB samples have an evenly distributed density during the hand-forming method in this fabrication stage.

RESULTS AND DISCUSSION

Table 2 shows the selection criteria for pre-treatment with sodium hydroxide through scanning electron miscroscopy (SEM). The SEM images of fibre treated with 0.4% NaOH show that the silica bodies were slightly removed with much remaining on the surface of the EFB fibre. Low NaOH concentrations in the pre-treatment cannot fully remove the silica bodies from the strand.

Table 2
Selection criteria for pre-treatment sodium hydroxide, NaOH

NaOH Treatment (%)	Untreated (UT)	Treated (0.4)
Scanning electron Microscopy (SEM)		

Observation and analysis of the hydration behaviour in terms of hydration properties, specifically, maximum hydration temperature and its necessary time to attain maximum temperature, the compatibility between cement and fibre and its enhancement with different types of accelerators can be explored (Amel et al., 2014). Recent research by Soh et al. (2018) revealed that the presence of hemicellulose, lignin, and extractives (oil, sugar, and starch) impacts the incompatibility of EFB fibre and cement. The heat of hydration of cement constituents influences cement formulation in various applications, along with its effectiveness in preventing water in cement paste from freezing in the winter and trying to improve the setting and hardening processes. Serious stress cracking can occur if heat is not easily depleted, especially for large structures. Thus, the adhesion of cement with natural fibre remains a major issue in the production of EFB fibre-cement board since adding a specific amount of natural fibre to a cement composition may cause a direct decrease in a compound's hydration temperature.

The hydration test was conducted in a sealable polyethene bag using 20g of EFB particles thoroughly mixed with 250g of Ordinary Portland cement (OPC). The mixture was then mixed with 114 mL of water for 2 minutes. The amount of water was calculated using 0.7 mL/g of EFB fibre (oven-dried basis) and 0.4 mL/g of cement. The samples were prepared in accordance with the fibre length. A thermocouple temperature (type K) is taped outside the sample bag immediately after thoroughly blending the mixture. The polyethene bag was neatly folded around the thermocouple to ensure that the temperature released by the mixture was correctly detected. The bag was then sealed inside a thermos flask and placed inside a polystyrene cup. Thermocouples were connected to the data logger (Graphtec GL240 Midi Logger) to record the temperature for each sample for 24 hours (Soh et al., 2018).

The hydration level of neat cement and cement-EFB fibre were monitored for 65 hours to track changes in the mixed material's temperature. Figures 4 and 5 show the hydration rate of the untreated and treated fibre using 0.4 % sodium hydroxide (NaOH).

The hydration rate for cement mixed with EFB fibre for passing R14M increased steadily for the first 11 hours at 44.9^{o}C for the treated fibre and 43.8^{o}C for the untreated fibre. The hydration temperature increases steadily for the treated fibre. Results show that the shortest fibre length R30M treated with 0.4% NaOH reached the maximum temperature of 47^{o}C after 11.2 hours. Meanwhile, the untreated fibre of the same retained mesh only reached 45.9^{o}C after 10.5 hours. Findings from this research are similar to Schackow et al. (2016) for the treated fibre, where the shorter the fibre length, the higher the hydration temperature was recorded.

According to Izani et al. (2013), the single fibre tensile test method determines natural fibres' modulus and tensile strength. Figure 6 shows the results of tensile strength using a single fibre strand done in this research based on the respective pre-treatment. The treated fibre shows higher tensile strength compared to the untreated fibres. In the recent research by Ramlee et al. (2019), the OPEFB was compared to sugarcane bagasse fibre.

This research has discovered that the presence of lignin affects the tensile strength of SCB fibre. Furthermore, SCB fibre contained more lignin than OPEFB fibres, and the tensile property of composites is influenced by the compatibility of the hydroxyl groups of lignin. Increased lignin content in the composite resulted in greater water absorption and swelling values. The lignin dispersion may have created voids that allowed water to be absorbed.

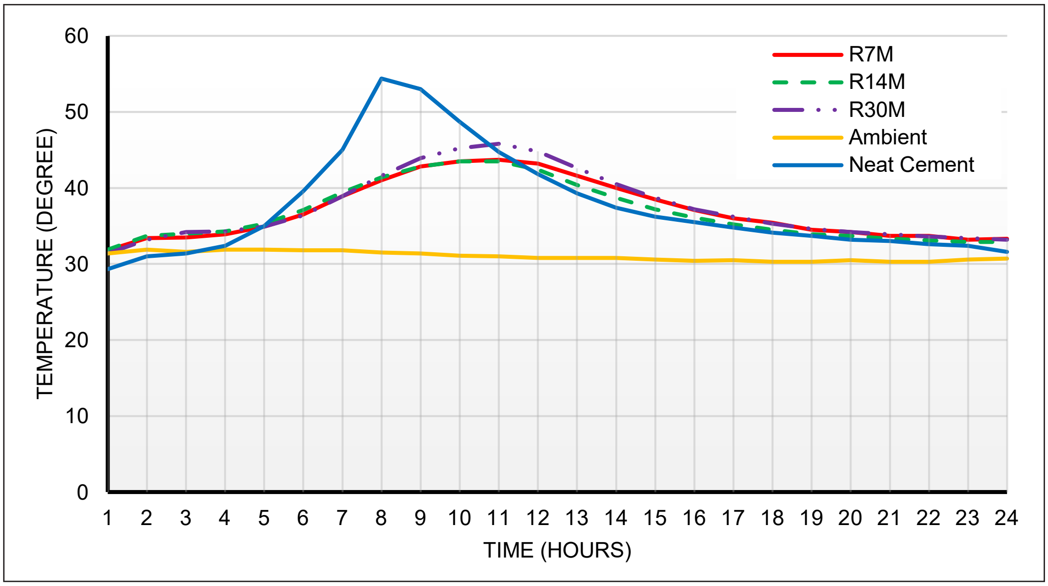


Figure 4. Hydration rate of 0% using different fibre length

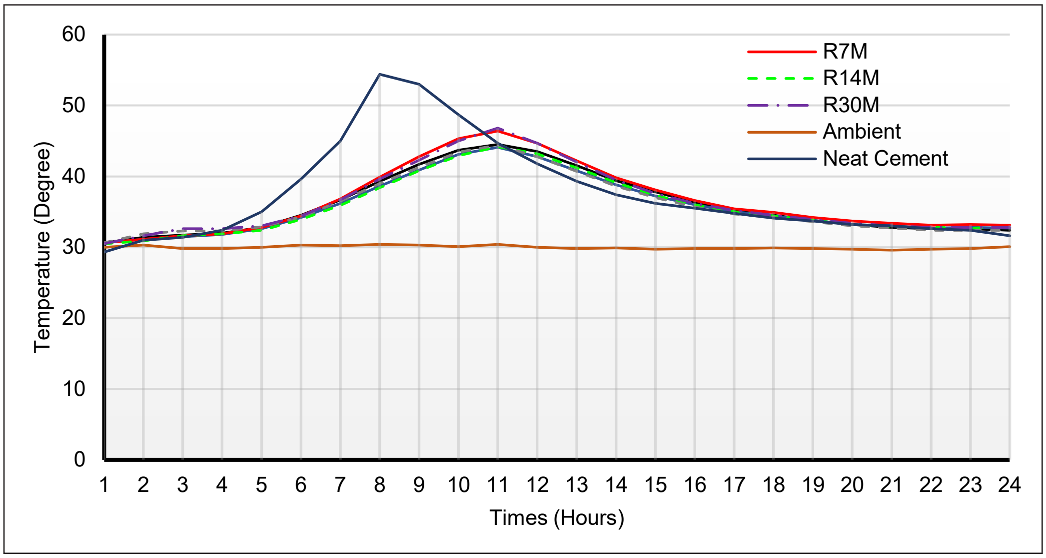


Figure 5. Hydration rate of 0.4% using different fibre length

Based on Figure 7, a moderate decrease in density was recorded by the OPEFB-CB composites using the treated fibres retained on R7M. From this result, the density of the sample decreased from 1,245.6 kg/m^3 to 1,155.6 kg/m^3. It is due to the presence of long fibres in the composite mixture that reduced the compaction between cement and fibre, hence affecting fibre distribution and resulting in large void spaces in the composite. The higher void content leads to lower composite density. According to Ramlee et al. (2019), EFB fibre board has a higher void content than sugarcane bagasse (SCB) and other hybrid EFB/SCB mixtures at the same fibre sieve size of ±13mm**.** The matrix's incompatibility causes high void formation with the fibre. Hence, this will result in a low internal bonding (IB) of the OPEFBCB. Since higher void content is most common in low-density materials, more areas were created, which allowed higher water absorption, thus an increase in the thickness swelling (TS) (Loh et al., 2010). According to Zuraida et al. (2011), long fibres will produce larger void spaces and consequently affect the density of the samples. Furthermore, based on the chemical constitution, EFB, which contained higher cellulose than the SCB,

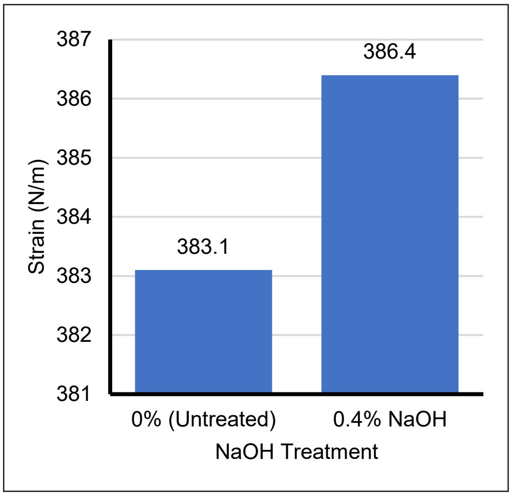
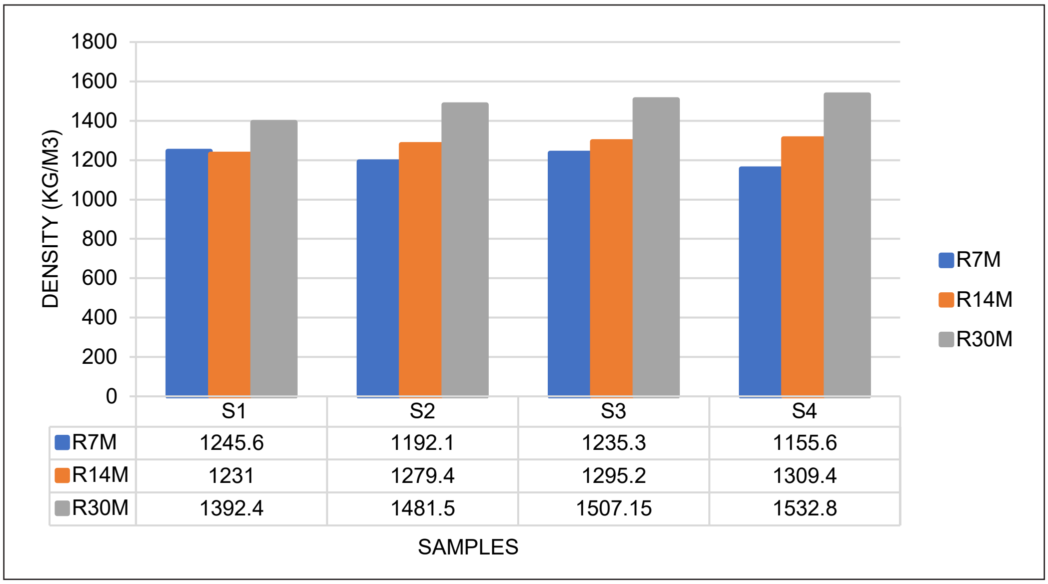


Figure 6. Tensile strength for single fibre with different percentages of NaOH Treatment



	S1	S2	S3	S4
R7M	1245.6	1192.1	1235.3	1155.6
R14M	1231	1279.4	1295.2	1309.4
R30M	1392.4	1481.5	1507.15	1532.8

Figure 7. Density distribution of OPEFB-CB composites

achieved higher specific strength, stiffness in the matrix and stability Ramlee et al. (2019). Meanwhile, the OPEFB-CB composites fabricated using the fibres retained on R14M (fibre size 3 mm) demonstrated better consistency in density distribution, ranging from 1,231 kg/m^3 to 1,309.4 kg/m^3 compared to the others.

The results of the thickness swelling for OPEFB-CB composites based on treated fibre are shown in Figure 8. In general, TS also represents the dimensional stability of OPEFB-CB composites. Longer fibres tend to ball up, reducing workability and strength (Zuraida et al., 2011). The shorter fibre used in the fabrication of OPEFB-CB significantly reduced the void spaces in the composite, thus resulting in less water being absorbed. High water absorption influences the composite's thickness, thus affecting its dimensions' stability. The effective moisture balance should be achieved continually after the thickness swelling test is conducted until a consistent weight is acquired (Fang et al., 2017). This research evidence that shorter fibre length demonstrated less TS effects on EFBCB.

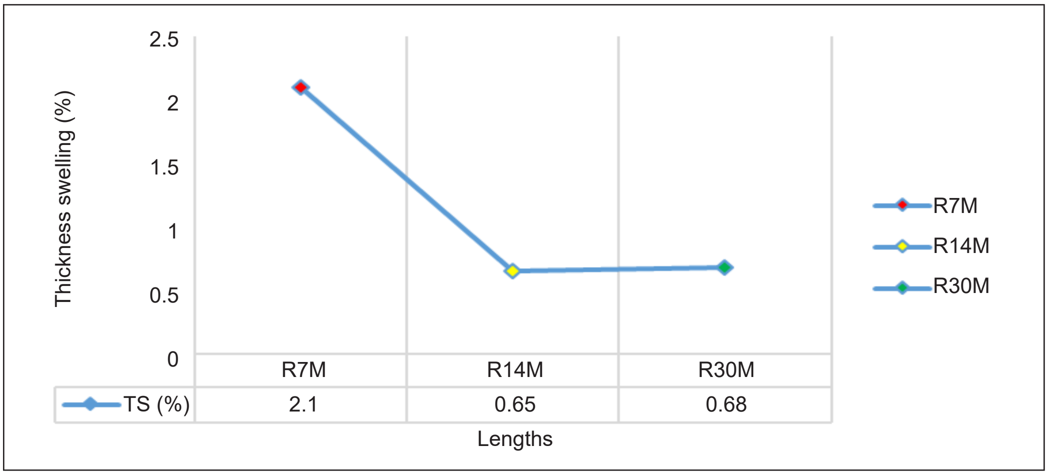


Figure 8. Average thickness swelling of OPEFB-CB composites

CONCLUSION

This research has revealed that the fibre length influenced the OPEFB-CB properties. The shorter fibre, which retains at R14M and R30M, results in a better density value near the target density of 1300 kg/m^3. Longer fibre lengths, particularly for fibre retained at R7M, result in a lower-density composite, thus creating more voids. Furthermore, shorter-treated EFB also results in higher hydration temperatures in the hydration test. Treated fibre removes the lignin layer and causes the cellulose content of OPEFBCB to increase and resulting in better tensile strength of a single fibre. It will allow better incompatibility between cement and fibre. The less void area in OPEFB-CB fabricated using shorter fibre also contributes to lower thickness swelling and gives better dimensional stability to the cement board.

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REFERENCES

Aanifah, F. J. M., Yee, P. L., Wasoh, H., & Abd-Aziz, S. (2014). Effect of different alkaline treatment on the release of ferulic acid from oil palm empty fruit bunch fibres. *Journal of Oil Palm Research*, *26*(4), 321-331.

Akasah, Z. A., Mohd, N., Nik, Z., & Dullah, H. (2019). The influence of oil palm empty fruit bunch fibre geometry on mechanical performance of cement bonded fibre boards. *International Journal of Mechanical Engineering and Robotics Research, 8*(4), 547-552. https://doi.org/10.18178/ijmerr.8.4.547-552

Amel, B. A., Paridah, M. T., Rahim, S., Osman, Z., Zakiah, A., & Ahmed, S. H. (2014). Effects of kenaf bast fibres on hydration behaviour of cement. *Journal of Tropical Forest Science*, *26*(3), 340-346.

Ayu, R. S., Khalina, A., Harmaen, A. S., Zaman, K., Isma, T., Liu, Q., Ilyas, R. A., & Lee, C. H. (2020). Characterization study of empty fruit bunch (EFB) fibers reinforcement in poly(butylene) succinate (PBS)/starch/glycerol composite sheet. *Polymers*, *12*(7), Article 1571. https://doi.org/10.3390/polym12071571

Elkordi, A. (2014). Alkali treatment of fan palm natural fibers for use in fiber reinforced concrete. *European Scientific Journal, 10*(12), 186-195.

Fang, T. W., Asyikin, N. S. S. N., Shawkataly, A. K. H. P., Kassim, M. H. M., & Syakir, M. I. (2017). Water absorption and thickness swelling of oil palm empty fruit bunch (OPEFB) and seaweed composite for soil erosion mitigation. *Journal of Physical Science*, *28*(2), 1-17.

Ibrahim, Z., Aziz, A. A., & Ramli, R. (2015). Effect of treatment on the oil content and surface morphology of oil palm (*Elaeis Guineensis*) empty fruit bunches (EFB) fibres. *Wood Research, 60*(1), 157-166.

Izani, M. N., Paridah, M. T., Anwar, U. M. K., Nor, M. M., & H'ng, P. S. (2013). Effects of fiber treatment on morphology, tensile and thermogravimetric analysis of oil palm empty fruit bunches fibers. *Composites Part B: Engineering, 45*(1), 1251-1257. https://doi.org/10.1016/j.compositesb.2012.07.027

Jeyapragash, R., Srinivasan, V., & Sathiyamurthy, S. J. M. T. P. (2020). Mechanical properties of natural fiber/particulate reinforced epoxy composites - A review of the literature. *Materials Today: Proceedings, 22*, 1223-1227. https://doi.org/10.1016/j.matpr.2019.12.146

Kaliwon, J., Ahmad, S. S., & Aziz, A. A. (2009). *Oil Palm Empty Fruit Bunch (EFB) as Energy*. Malaysian Palm Oil Board.

Kochova, K., Schollbach, K., & Brouwers, H. J. H. (2015, September 16-18). Use of alternative fibres in Wood Wool cement boards and their influence on cement hydration. In *Proceedings of the 19th International Conference on Building Materials, Ibausil* (pp. 1375-1382). Bauhaus University, Weimar, Germany.

Loh, Y. W., H'ng, P. S., Lee, S. H., Lum, W. C., & Tan, C. K. (2010). Properties of particleboard produced from admixture of rubberwood and Mahang species. *Asian Journal of Applied Sciences, 3*(5), 310-316.

Onuorah, E. O., Okeke, C. A., Nwabanne, J. T., Nnabuife, E. L. C., & Obiorah, S. O. M. (2016). The effects of production parameters on properties of single and 3-layer cement-bonded composites made from oil palm empty fruit bunch and tropical hardwood sawmill residue. *World Journal of Engineering*, *12*(6), 577-590. https://doi.org/10.1260/1708-5284.12.6.577

Ramlee, N. A., Jawaid, M., Zainudin, E. S., & Yamani, S. A. K. (2019). Tensile, physical and morphological properties of oil palm empty fruit bunch/sugarcane bagasse fibre reinforced phenolic hybrid composites. *Journal of Materials Research and Technology*, *8*(4), 3466-3474. https://doi.org/10.1016/j.jmrt.2019.06.016

Schackow, A., Effting, C., Gomes, I. R., Patruni, I. Z., Vicenzi, F., & Kramel, C. (2016). Temperature variation in concrete samples due to cement hydration. *Applied Thermal Engineering, 103*, 1362-1369. https://doi.org/10.1016/j.applthermaleng.2016.05.048

Soh, N. M. Z. N., Akasah, Z. A., Dullah, H., Aziz, A. A., & Aminudin, E. (2018). Alkaline treatments on EFB fibre: The effect on mechanical-physical properties and fibre-cement hydration rate. *Malaysian Construction Research Journal*, *4*(2 Special Issue), 117-128.

Sugiman, S., Setyawan, P. D., & Anshari, B. (2019). Effect of fiber length on the mechanical properties and water absorption of bamboo fiber/polystyrene-modified unsaturated polyester composites. In *IOP Conference Series: Materials Science and Engineering* (Vol. 532, No. 1, p. 012008). IOP Publishing.

Supranto, S., Tawfiequrrahman, A., Yunanto, D. E., & Kurniawan, I. (2014, December 2-3). Oil palm empty fruit bunch fiber conversion to high refined cellulose using nitric acid and sodium hydroxide as the delignificating agents. *AUN/SEEED-Net Regional Conference on Chemical Engineering* (pp. 1-15). Yogyakarta, Indonesia.

Zuraida, N., Sopyan, I., & Zahurin, H. (2011). Effect of fiber length variations on mechanical and physical properties of coir fiber reinforced cement-albumen composite (CFRCC). *IIUM Engineering Journal, 12*(1), 65-77.