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ASSESSING THE POTENTIAL OF INCORPORATING EMPTY FRUIT BUNCH (EFB) INTO CEMENT BOARDS TREATED WITH HOT WATER AT DIFFERENT TEMPERATURES AND SOAKING TIMES

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Graphical abstract

Abstract

Empty Fruit Bunch (EFB) was incorporated into cement boards to evaluate its effect on thickness swelling (TS), modulus of rupture (MOR) and internal bonding (IB), using two different soaking durations; two and three hours at three temperatures: 75°C, 85°C, and 95°C. The objective of this study was to explore the potential of hot water treatment as a cost-effective alternative to chemical treatment, which typically incurs additional expenses. The testing conducted accordance to British Standard (BS) and European Norms (EN). The samples were fabricated with target density of 1300 kg/m³. At the 2-hour soaking, density recorded in ranges from 1231.54 kg/m³ to 1391.31 kg/m³, while at 3 hours, it ranges from 1015 kg/m³ to 1431.29 kg/m³. TS values remain relatively low overall, falling between 0.01% and 0.1%. However, TS rate decreased as soaking time increased, indicating that shorter soaking durations led to greater swelling of the EFB board. Prolonged soaking time able to increase IB at low temperature of 75°C compared to high temperature of pre-treatment in hot water. It has been demonstrated that hot water treatment is a viable method for treating EFB, as the incorporation of EFB able to enhance both the physical and mechanical properties of the material. This suggests its strong potential as a sustainable material for use in construction applications.

Keywords: Empty fruit bunch cement board (EFBCB), hot water treatment, thickness swelling (TS), modulus of rupture (MOR) and internal bonding (IB).

1.0 INTRODUCTION

Malaysian Palm Oil Board (2024) claimed the tree of palm oil or also known as *Elaeis guineensis* is planted on the land covered 5.67 million hectares and earnings income from RM108.52 billion in 2021 to RM137.89 billion in 2022 shows huge potential in exporting the palm oil byproducts including palm oil itself [1]. Consequently, oil palm industries generated the solid wastes consists of empty fruit bunch (EFB), mesocarp fruit fibers (MP), palm kernel shells (PKS) and palm oil mill effluent (POME) [1-4]. Generally, all these wastes were composted together with additional organic material to produce high nutrient fertilizer (2,5] and produce biogas as well as biodegradable polymer by mixing with tapioca starch due to high cellulose contents of EFB [6].

However, the issues of disposal are still need to overcome in order to minimise the environmental pollutions due to harmful effects to air quality, humans and surroundings [8-9]. Therefore, utilization of application EFB as cement board can helps to minimize the environmental impacts and depletion of resources. Previous study [7-14] investigated the effect of incorporation EFB in cement board, medium density fiber board and insulation boards to thickness swelling (TS), modulus of rupture (MOR) and internal bonding (IB). Finding showed the

TS of cement boards was reduced in the range of 0.65% to 1.82% when optimum length of EFB with 3mm was incorporated [12]. It was also produced high IB and modulus of elasticity. Four factors contribute good findings when EFB incorporated in cement board namely was soaking temperature [10], soaking time [15], density of cement board [16] and type of treatment on EFB [9,10]. The pre-treatment of EFB with sodium hydroxide (NaOH) concentration and water treatment and it was able to reduce TS to 0.5% [10]. While (Ibrahim et al., 2020) completed the treatment of EFB with NaOH and acetic acid was also able to produce significant findings of MOR and IB. Soaking times less than 7 hours generally able to enhance the mechanical properties of cement board [15]. However, (Faizi et al., 2013) claimed the longer soaking time will be reduced the mechanical properties due to increment rate of water absorption. It can be concluded that chemical treatment was more popular and commonly chosen by few researchers as pre-treatment of EFB while other method such as immersion of hot water method was less published compared to other methods.

In this present study, the investigation was conducted to study the potential of EFB incorporated in cement board in enhancing the thickness swelling (TS), modulus of rupture (MOR) and internal bonding (IB) by conducting two different soaking time namely in two and three hours in three temperatures of 75°C, 85°C and 95°C. The objective of this study was to investigate the potential of using hot water treatment on EFB to minimize costs, as chemical treatment would require additional expenses.

2.0 METHODOLOGY

This section describes the preparation of empty fruit bunch (EFB), treatment of EFB fiber, process performed in fabricating the empty fruit bunch cement board (EFBCB), size dimensions and total samples required for laboratory testing.

2.1 Preparation of Empty Fruit Bunches (EFB)

Raw materials of EFB were collected from oil palm factory and transported to Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia (UTHM). The process conducted in preparing EFB is shown in Figure 1. The EFB required to sun-dried for 2 to 3 days to remove excessive moisture contents. After drying, the EFB was shredded into smaller and finer size using shredder and hammer mill machine. EFB fiber was shredded in wood mould containing wire mesh to remove any unwanted substance, making it ready for the treatment of hot water. This process is crucial for reducing excessive moisture contents of EFB and ensuring the good bonding between EFB fiber and cement during process of fabrication cement board. Similarly process also conducted by Ridzuan et al., (2023) and Maynet et al., (2023).

(a) (b) (c)

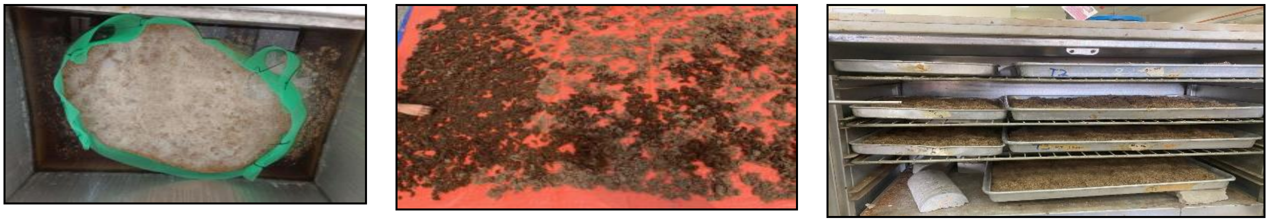
Figure 1 Process conducted in preparing EFB. (a) Sun dried of EFB, (b) Shredding using shredder and hammer mill and (c) Sieving of EFB fiber

2.2 Treatment of EFB Fibers

Figure 2 shows an empty fruit bunch (EFB) fibers was treated in the hot water tank in order to remove any impurities and lignin, wax and oil contents of EFB. The EFB fiber was submerged at three different temperatures of hot water namely was 75°C, 85°C and 95°C and soaked at 2 and 3 hours. This type of treatment was differ compared to [7,9,10,13,14,17] which was treated in sodium hydroxide (NaOH) solution with 0.2% to 10% concentration by weight of water. In this present study, the selection of hot water treatment is due to reasons of cost-effective method and contribute to environmental benefits. (Norul Izani et a., 2013 and Pangsana et al., 2019) investigated the effect to damage morphologies when EFB fiber was treated with different treatment, concluded that Scanning Electron Microscopy (SEM) image shows the EFB fiber treated with hot water more cleanliness than untreated fibers. Hot water treatment able to remove some of wax [18], fatty substances and tyloses or bulging cell wall that may contains starch, resin or gum [19].

2.3 Preparation of Cement Board

Total of nine main samples with dimension of 350 x 350 x 12 mm were prepared after being oven-dried as shown in Figure 3. Table 1 calculates contents required for EFB fiber, cement and water accordance to the ratio of cement and fibre, 3.5:1 based on the designated density 1300kg/m^3. Same proportion was also prepared by Ogunjobi et al., (2019) and Owoyemi et al., (2020). Figure 4(a) shows the EFB fibers, cement and water were weighted and mixed followed the designated mix. The remaining water were poured gradually and blended using mechanical mixer at about 5 minutes as can be seen in Figure 4(b). Immediately, the mixture transferred to wood mould with dimension size 400 x 400 mm to undergone the process of spreading and flattening as shown in Figure 4(c). After the EFB mixtures was flattened by hand (Figure 4(d)), the surface of cement board was covered with polythene sheet prior compacting process.



(a) **(b)** **(c)**

Figure 2 Process conducted in treating EFB using hot water tank started with (a) EFB fiber was immersed and soaked for 2 and 3 hours in water bath tank for three temperatures 75°C, 85°C and 95°C, (b) Sun dried after soaking process was completed and (c) Oven dried

Table 1 Design mix of EFBCB for one sample

Sample size	350 x 350 x 12 mm
Volume sample, V	1.47×10^{-3} m^3
Dry weight, Vρ	1911g
Cement : EFB	3.5:1
EFB fiber weight, x	3.5x + x = dry weight 4.5x = 1911 x = 424.67g @ 0.42kg
Cement weight, 3.5x	3.5 (0.42) = 1.5kg
Distilled water contents	0.4 (cement)+0.3 (EFB)= 0.72kg

The wood mould containing EFB mix was underlaying on the steel and clamped with bolts (Figure 4(e)). The EFBCB was compressed to the specified thickness 12 mm ± 1mm at pressure rate of 180 mm/min (Figure 4(f)). The mould was leaved for 24 hours and then demoulded. The EFBCB was cured at room temperature for 28 days (Figure 4(f)). During cutting process (Figure 4(g)), nine main samples of EFBCB was cut based on the layout as shown in Figure 3 with dimension 350 x 350 mm. Then, the main samples were cut to selected dimension accordance to BS EN 323-1993 as shown in Table 2 and it was being ready to underwent the physical and mechanical testing name as density, thickness swelling, modulus of rupture and internal bonding (Figure 4(h)).

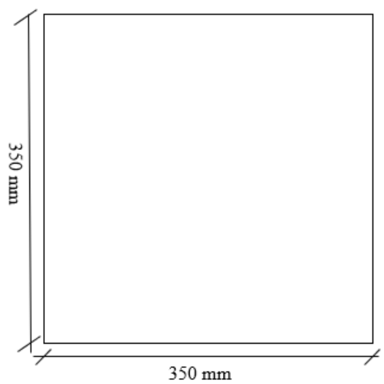
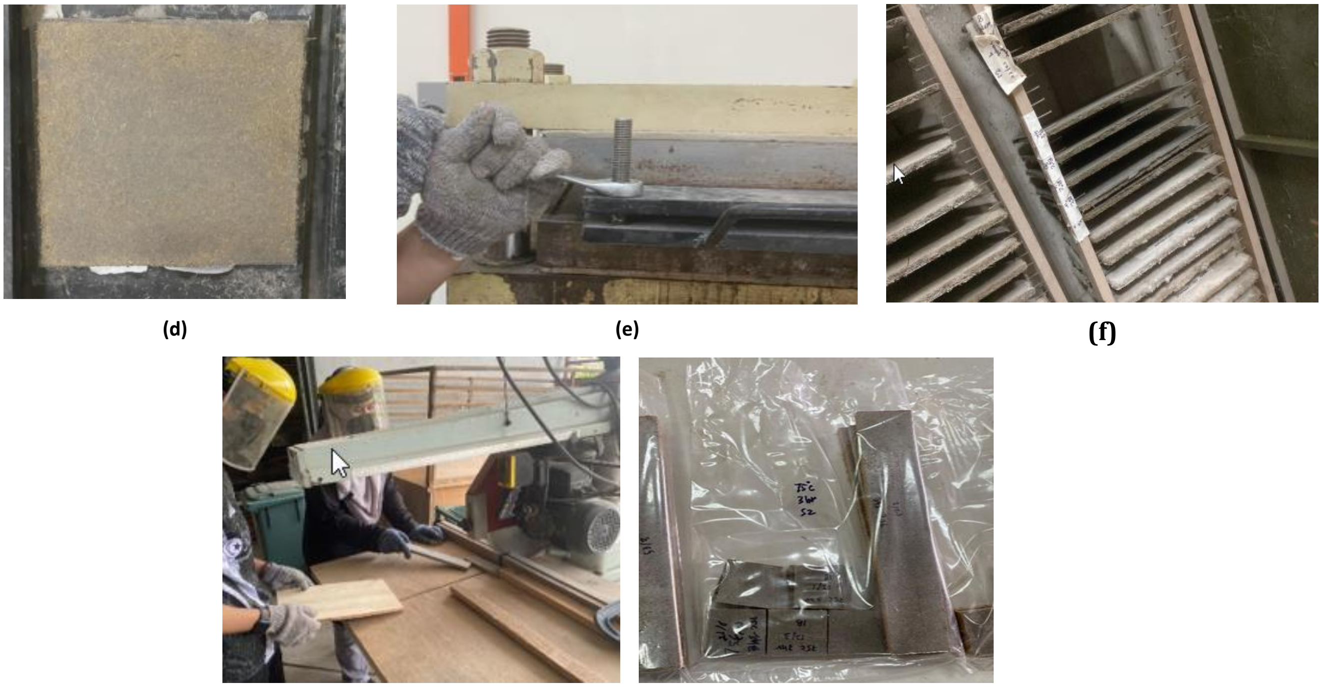


Figure 3 Cutting layout on main samples of EFBCB (350 x 350 mm)

(a) **(b)** **(c)**



(d) (e) (f)

(g) (h)

Figure 4 *Process of fabrication EFBCB. (a) Weighting materials of EFB fiber, cement and water, (b) Mixing process, (c) Spreading and flattening process, (d) Pre-compact process, (e) Clamping and compacting process, (f) Curing process, (g) Cutting process and (h) Samples was ready for laboratory testing*

Table 2 Total of samples and dimension prepared for physical and mechanical properties

Types of test	Size dimension (mm^3) length x width x thickness	Total of samples for 75°C, 85°C and 95°C	
		2 hrs	3 hrs
Density	50 x 50 x 12	5	5
Thickness swelling	50 x 50 x 12	5	5
Modulus of rupture	300 x 50 x 12	2	2
Internal bonding	300 x 50 x 12	3	3

2.4 Testing on EFBCB

The testing conducted were the density, thickness swelling (TS), modulus of rupture (MOR) and internal bonding (IB). Equation 1 presents the formula used, in accordance with BS EN 323:1993, to determine the density of EFBCB. The volume of EFBCB is calculated by measuring the dimensions b_1, b_2, and thickness.

$$Density, \rho \ (kg/m^3) = \frac{m}{b_1.b_2.t} x \ 10^6 \quad (1)$$

Where:
m=mass of board in gram
b_1, b_2, t = sides width and thickness in mm

Thickness swelling was calculated based on Equation 2, in accordance with BS EN 317:1993, by measuring the thickness of EFBCB using vernier clippers before and after immersion in hot water for soaking times of 2 and 3 hours.

$$Thickness \ swelling(\%) = \frac{t_2 - t_1}{t_1} x \ 100 \quad (2)$$

Where :
t1 = thickness before immersion (mm)
t2 = thickness after immersion (mm)

The modulus of rupture (MOR) represents the strength of a material just before it fails under a bending force. It is a crucial parameter for assessing the flexural strength of cement boards, as it indicates the material's ability to resist bending or fracturing under structural loads. Equation 3 shows formula used accordance to BS EN 310:1993.

$$Modulus \ of \ rupture \ (MOR) = \frac{f_{\max} . \ l}{b.f^2} \quad (3)$$

Where;
MOR = modulus of rupture in N/mm^2
f_{max} = maximum load applied in N
l =effective span or length between supports in mm
b =width of board in mm
f =thickness of board in mm

Internal bonding (IB) or the tensile strength of EFBCB, was measured in accordance with BS EN 319:1993 as shown in Equation 4, which specifies testing perpendicular to the board surface.

$$Internal\ bonding(IB) = \frac{Pw}{l} \quad (4)$$

Where;
IB= Internal bonding strength in N/mm^2
P = load applied in N
w = width of bonded area in mm
l = length of bonded area in mm

Figure 5 shows the setup of EFBCB samples on the Universal Testing Machine (UTM), INSTRON 3369, for determining the MOR and IB strength.

Figure 5 Experimental test setting

3.0 RESULTS AND DISCUSSION

This section summary the investigation on physical and mechanical properties of EFBCB. Table 3 shows the results findings of density and thickness swelling (TS) due to different temperature of hot water tank; starts with 75°C, 85°C and 95°C and soaking at 2 and 3 hours. Three samples of each temperature were prepared for different density and soaking time. Result reveals variations in both density and TS across different temperature and time intervals, with standard deviations highlighting the spread of the measurements. For example, at the 2-hour soaking, density ranges from 1231.54 kg/m³ to 1391.31 kg/m³, while at 3 hours, it ranges from 1015 kg/m³ to 1431.29 kg/m³. TS values remain relatively low overall, falling between 0.01% and 0.1%. The varying standard deviations indicate differing levels of consistency in the results.

Table 3 Density and thickness swelling (TS) of EFBCB at different temperatures (starts with 75°C, 85°C and 95°C) and soaking time at 2 and 3 hours

Density (kg/m³)		TS (%)	
2hrs	3hrs	2hrs	3hrs
1241.01(12.25)	1173.22(33.93)	0.03 (0.01)	0.012(0.004)
1277.3 (20.8)	1389.14(79.86)	0.02 (0.006)	0.011(0.003)
1303.34(56.2)	1431.29(49.51)	0.02(0.006)	0.016(0.012)
1231.54(86)	1235.38(2.81)	0.03(0.026)	0.019(0.002)
1300.12(66.5)	1247.73(39.14)	0.02(0.01)	0.023(0.012)
1293.39(36.5)	1214.9(25.45)	0.02(0.014)	0.018(0.006)
1386.44(53.13	1239.21(77.67)	0.02(0.038)	0.045(0.01)
1391.31(48.1)	1166.69(56.11)	0.01(0.044)	0.033(0.009)
1303.29(40.01)	1015(94.6)	0.1(0)	0.058(0.011)

Note: Standard deviation is shown in bracket

Figure 6 shows the influences of different temperature of hot water and soaking time to density of EFBCB. High temperatures of soaking and soaking time enhance the density of cement board containing EFB. Previous study also showed the temperature of pre-treatment of EFB at 60°C able to increase density of cement board [10]. The soaking duration affected the density of EFBCB might be due to increased moisture removal, which in turn influenced the board's weight [22].

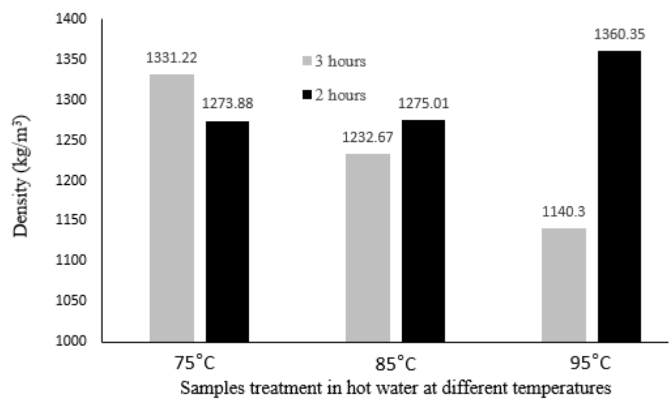


Figure 6 Density of EFBCB influences to different temperatures of hot water and soaking time

Figure 7 illustrates the effects of varying hot water temperatures and soaking durations on thickness swelling (TS) over a 28-day period. The TS rate decreased as soaking time increased, indicating that shorter soaking durations led to greater swelling of the EFB board. This finding contrasts with previous studies [22,23], which may be attributed to differences in pre-treatment methods, variations in surface characteristics influencing water absorption or differing environmental conditions during testing. In contrast, TS increased with rising water temperatures. Nonetheless, all samples remained within the maximum TS limit of 1.5% as specified by BS EN 323:1993. These results suggest that soaking durations of 2 to 3 hours could be effectively used in future hot water treatments of EFB boards.

Study of [7] concluded that NaOH treatment resulted in the lowest thickness swelling (TS), with only an 8% increase compared to the EFB board treated with hot water. Teh et al. (2017) reported that TS values for EFB boards ranged between

4% and 13% for both treated and untreated samples using NaOH, which is still higher than the values observed in this present study. Therefore, it can be concluded that hot water treatment is effective in producing low thickness swelling (TS), which is a good indicator reduced swelling in the EFBCB.

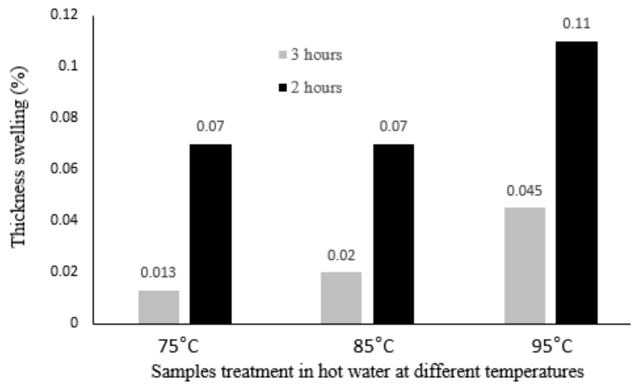


Figure 7 Thickness swelling (%) of EFBCB influences to different temperatures of hot water and soaking time

Moreover, the inconsistent trend is recorded due to the large gap in the standard deviation was noticed in Table 4 for the temperature at 75°C. MOR results appear to be an outlier, as extreme values fall outside the expected range for both soaking times. Therefore, further replication of the experiments may be needed to confirm this. While, high IB was recorded when EFBCB soaking for 3 hours compared to 2 hours soaking time. However, with the increment of soaking temperature up to 95°C indicated decrement of IB when EFBCB soaked in 3 hours.

Table 4 Modulus of rupture (MOR) and internal bonding (IB) of EFBCB at temperatures (starts from 75°C, 85°C to 95°C) and soaking time at 2 and 3 hours

MOR		IB	
2hrs	**3hrs**	**2hrs**	**3hrs**
48.99(3.82)	43.61(37.97)	0.089 (0.009)	1.734 (1.44)
65.23(18.48)	355.9(298.17)	0.353 (0.41)	1.566(1.33)
41.78(4.95)	265.1(139.75)	0.05(0.043)	1.469(1.57)
5(1.03)	4.96(1.09)	0.428(0.397)	0.204(0.099)
4.95(1.07)	2.82(0.67)	0.317(0.308)	0.542(0.59)
4.01(0.48)	4.69(1.06)	0.086(0.03)	0.118(0.04)
5.03(4.23)	4.28(1.29)	1.467(1.22)	0.146(0.024)
5.33 (1.86)	4.13(0.92)	1.099(1.45)	0.161(0.026)
4.51 (1.75)	3.53(0.603)	0.932(0.81)	0.204(0.099)

Note: Standard deviation is shown in bracket

Overall, the incorporation of EFB in cement board shows the potential in future as sustainable materials. The ideal soaking time was 3 hours based on lower value of thickness swelling associated with lower temperature of 75°C. The high temperature makes high water absorption and it give the impact to thickness swelling [7]. While, prolonged soaking time able to increase internal bonding at low temperature of 75°C compared to 85°C and 95°C which is classified as high temperature. Similar trends also observed with higher soaking temperature improved the modulus of rupture (MOR) of EFBCB. It can be concluded that ideal temperature for hot water treatment is 75°C and 3 hours of soaking time. This hot water treatment able to reduce the inhibitory substances and oils in the fiber.

4.0 CONCLUSIONS

The objective of this study is to investigate the potential use of hot water treatment on EFB has been successfully achieved, as the findings demonstrate a significant reduction in thickness swelling (TS) and improvements in both modulus of rupture (MOR) and internal bonding (IB). The TS remained consistently low, ranging between 0.01% and 0.1%, which is notably lower than values reported in previous studies. Therefore, hot water treatment presents a viable alternative to chemical treatments, which often involve additional costs. However, further validation through extended testing and long-term durability assessments is recommended to reinforce these promising results. Additionally, future research should include an internal microstructural analysis of the cement boards containing EFB to better understand the bonding interaction between the fiber and cement matrix.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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