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Utilization of Oil Palm Empty Fruit Bunch in Cement Bricks

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Abstract: Oil palm empty fruit bunch (EFB) is a biomass waste abundantly produced by the oil palm industry in Malaysia. To minimize the environmental impacts, it needs to be properly disposed of or being rapidly consumed as a raw material of another industry. This study investigated the feasibility of substituting EFB in cement bricks, which is in high demand by the construction industry. A total of 120 specimens having the cement-to-sand (c/s) ratios of 1:2.5 and 1:3 were produced in the laboratory. EFB fibre was used to replace 10% to 25% of sand in the mix by volume. The specimens were tested for the compressive strength, density and water absorption after 28 days of casting. For the mix of 1:2.5 c/s ratio, 25% EFB content reduced 22% of density, decreased 59% of compressive strength and increased 43% of water absorption capacity of normal cement brick. This was mainly attributed to the porous cellular structure of EFB fibre that created a large volume of voids in the mix. Based on the feasibility evaluation, EFB fibre can only replace up to 15% and 10% of sand in the mixes of 1:2.5 and 1:3 c/s ratios respectively.

Keywords: *cement brick; empty fruit bunches; oil palm; partial sand replacement*

1. Introduction

Malaysia is the second-largest oil palm producer in the world contributing 19.9 million tonnes of crude palm oil in 2019 (Malaysian Palm Oil Board, 2020) [1]. At the same time, an enormous sum of oil palm empty fruit bunch (EFB) is produced as the biomass waste, which comprises 22% to 25% of the total weight of the fresh fruit bunch [2].

This biomass waste needs to be properly disposed of, to minimize the environmental impact. However, due to low awareness, only 30% of palm oil mills in Malaysia are involved in recycling activities of EFB [3]. EFPs are normally left rotting at the plantation sites [2], and this attracts pests and leads to fouling [4]. EFB may be used as the fuel to generate steam at the mills, the organic fertilizer, the animal fodder, the growth media for fungi and plants and the mat-making materials [2, 4, 5]. However, the consumption rate is relatively low compared with its production rate.

Recently, there were studies about adding EFP in bricks and blocks [4, 6-8], which gave an alternative application of EFP. Since bricks constitute about 25% materials of a typical building structure [9], and the construction industry in Malaysia is rapidly growing, successful application of EFB in brick would speed up its consumption and resolve the disposal and environmental issues.

This study investigated the feasibility of using EFB as a raw material to produce cement brick. It was used to partially replace the sand used in the mix. The bricks with various EFB content were fabricated in the laboratory and tested for the compressive strength, density and water absorption.

2. Materials and methods

2.1. Materials

Ordinary Portland cement (OPC) was used as the cementitious binder for the sand and EFB. It conformed to MS EN 197-1:2014 for the strength class 42.5 N/mm^2.

Empty fruit bunch (EFB) was oven-dried at the temperature of 100°C to 115°C for at least 24 hours (Fig. 1.). They were ensured separated, free from soil and dirt and cut into an average length of 40 mm (Table 1).

Table 1. Properties of EFB fibres

Properties	Values
Average fibre length (mm)	40 mm
Average Diameter (mm)	0.14 mm
Density (compacted*)	120 kg/m^3
Average fibre length (mm)	40 mm

**Note: The density was obtained from the same compaction method used to produce brick specimens in this study*

(a) Drying EFB Fibre (b) Mixing (c) Compressive test

Fig. 1. Preparation and testing of the specimens

River sand (≥90% passing the 600 μm sieve) was used in the mix. It was kept air-dried at the room temperature without direct exposure to the weather. The domestic portable water was used for mixing and curing of the brick.

2.2. Mix proportion

The brick specimens were produced into two grades, namely the cement-to-sand (c/s) ratios of 1:2.5 and 1:3 by volume (Table 2). The water-to-cement (w/c) ratio was 0.5. Specimens C1 and C2 acted as the control specimens without EFB fibre in the mixes. EFB fibres were used to replace 10% to 25% of sand in the mix to produce the test specimens, which were denoted as E1 and E2.

Each mix proportion comprised 12 specimens; 9 specimens were tested for the compressive strength on days 3, 7 and 28, and another 3 specimens were used to determine the density and water absorption on day 28. Average values of 3 specimens were taken for all the results.

Table 2. Number of specimens tested

Cement-Sand Ratio	Specimen	EFB content (%)	No. of specimens
1: 2.5	C1	0	12
	E1-10	10	12
	E1-15	15	12
	E1-20	20	12
	E1-25	25	12
1: 3.0	C2	0	12
	E2-10	10	12
	E2-15	15	12
	E2-20	20	12
	E2-25	25	12
		Total	120

2.3. Test procedures

The specimens were cast in the working size of 215 mm x 102.5 mm x 65 mm by using custom-made steel moulds at the room temperature of 30 ± 5°C with a relative humidity of 60-80% following the relevant standards [10-12]. The mix was compacted in 3 layers, each was uniformly compacted with 25 strokes of rod compactor. The specimens were de-moulded a day later and cured in water until the specimens were tested.

The specimens were tested for compressive strength by using a compression machine (Brand: ELE International, Capacity: 3000 kN). The compressive stress, σ_i, was determined by dividing the ultimate load, P_i, with the contact surface area of the specimen, A (Eq. 1).

$$\sigma_i = \frac{P_i}{A} \tag{1}$$

Electric balance (capacity: 30 kg, accuracy = ±0.001 kg) was used to determine the mass of the specimens under different conditions for computing the density, ρ, and water absorption, WA, of the specimens (Eqs 2 and 3).

$$\rho = \frac{w_d}{w_s - w_i} \times 100\% \tag{2}$$

$$WA = \frac{w_s - w_d}{w_d} \times 100\% \tag{3}$$

where: W_i = mass of the immersed specimen, kg
W_s = mass of the saturated specimen, kg
W_d = mass of the oven-dry specimen, kg

3. Results and discussions

3.1. Dimensions

The dimensions of the specimens measured by an electronic Vernier calliper on day 28 are given in Table 3. Presumably, the variations with the working size of 215 mm x 102.5 mm x 65 mm were due to expansion of the specimens after compaction, and during the hydration and hardening processes of the mix.

It was found that the specimens with a higher EFB fibre content endured a larger degree of expansion. Specimens E1-25 and E2-20 having the highest EFB fibre content were the largest sizes in their respective series.

Table 3. Dimensions of the specimens on day 28

Cement-Sand Ratio	Specimen	Length, *l* (mm)	Width, *b* (mm)	Height, *h* (mm)	Volume, V (mm^3)
1: 2.5	C1	215.0	102.0	65.0	1425450
	E1-10	215.0	102.3	65.0	1429643
	E1-15	215.0	102.5	66.0	1454475
	E1-20	216.0	102.5	67.0	1483380
	E1-25	216.5	103.0	67.0	1494067
1: 3.0	C2	215.0	102.0	65.0	1425450
	E2-10	215.0	102.0	65.0	1425450
	E2-15	215.0	103.0	65.0	1439425
	E2-20	216.0	103.0	66.5	1479492
	E2-25	-	-	-	-

*Note: [1]Volume of the specimen, $V = l \times b \times h$

[3]The specimens collapsed during de-moulding. The dimension was not measured.*

This was mainly due to the compressibility characteristic of EFB fibre in the mix. The cellulous fibre structure partially recovered from the compressive deformation almost immediately after the removal of the compacting pressure (Fig. 2). As the height of the specimen, *h*, was not restrained by the steel mould, it endured the largest expansion of 2 mm as compared with 1.5 mm and 0.5 mm for the length, *l*, and width, *b*, respectively (Table 3). The expansion in terms of the length and width occurred after de-moulding before complete hardening of the mixture.

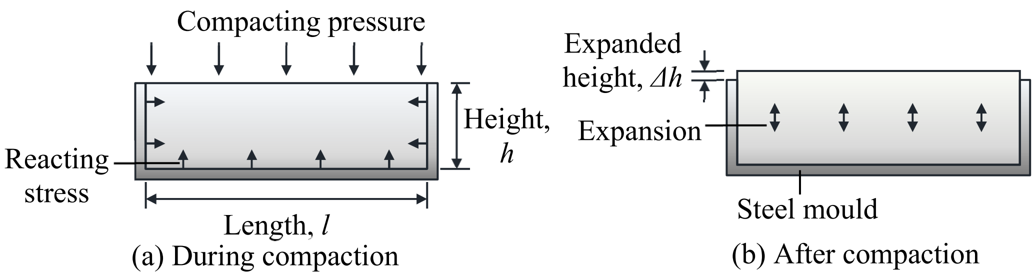


Fig. 2. Expansion of specimen after removal of compacting pressure

3.2. Compressive strength

The compressive strengths of the specimens are presented in Table 4. The strength generally increased with age, reaching about 1/3, 2/3 and full strength on days 3, 7 and 28 respectively, as expectable from a typical cementitious mix. This implied a good consistency of the quality of cement.

The cement acted as the binder to the sand and EFB fibre. For a higher cement content in the mix, the specimens with the c/s ratio of 1:2.5 were always stronger than 1:3 (Table 5). As the EFB content increased from 0% to 20%, the strength difference between the two mixes reduced from 21% to 5%.

The sand replacement by EFB fibre was found reducing the compressive strength of the specimen. Specimens E1-20 and E2-20 demonstrated a significant loss of strength by 50% and 43%

respective when 20% of sand was replaced by EFB fibre. The reduction was almost proportional to the EFB fibre content in the mix (Fig. 3).

Table 4. Test results

Specimen	Compressive Strength, σ (N/mm^2)			Density, ρ (kg/m^3)	Water Absorption, WA (%)
	Day 3	Day 7	Day 28	Day 28	Day 28
C1	3.3	6.56	11.6	1859	17.1
E1-10	2.8	5.6	9.3	1720	17.7
E1-15	2.8	5.4	7.5	1550	18.4
E1-20	2.2	4.8	5.8	1477	21.2
E1-25	1.8	3.2	4.8	1447	24.5
C2	3.0	6.2	9.6	1654	17.8
E2-10	2.6	5.0	7.9	1610	19.8
E2-15	2.5	4.5	6.8	1497	21.6
E2-20	1.7	3.6	5.5	1450	22.6
E2-25*	-	-	-	-	-

**Note: The specimen collapsed during demoulding. The specimens were not tested and no result was obtained.*

Table 5. Compressive strengths of specimens with different EFB content at day 28

EFB content (%)	c/s ratios		Strength ratio, $R_s = \frac{\sigma_{E1}}{\sigma_{E2}}$
	1:2.5	1:3	
0	11.6	9.6	1.21
10	9.3	7.9	1.18
15	7.5	6.8	1.10
20	5.8	5.5	1.05
25	4.8	-	-

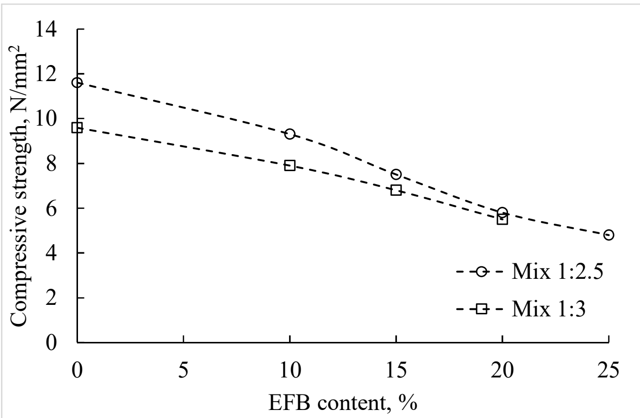
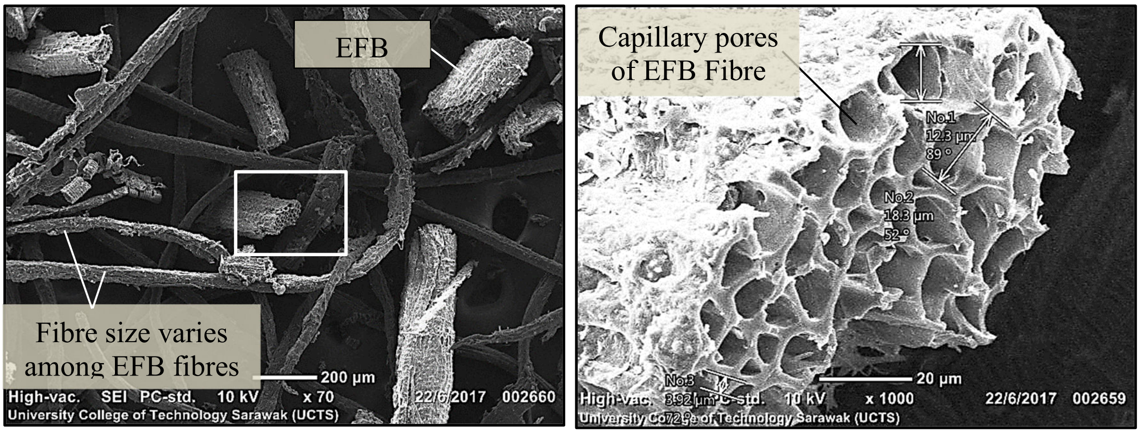


Fig. 3. Effects of EFB on compressive strength (day 28) of the specimen

This was due to the inferior physical and mechanical properties of EFB fibre as compared with the sand. EFB fibre appeared as a porous cellulous structure made of an enormous amount of ligneous-like micro-fibres (Fig. 4) [6]. Its density and hardness were significantly lower than the sand, which resulted in a low compressive strength of EFB fibre. Also, the cellulous structure may affect the bond with the cement matrix.



(a) Magnification x70 (b) Magnification x1000

Fig. 4. Micro-structure of EFB fibre [6]

EFB fibre affected the workability and compaction quality of the fresh mix. This was observed from specimens E2-25 with c/s ratio of 1:3. The porous cellulous structure of EFB fibre absorbed the free water in the fresh mix, which caused the mix to be rather dry during casting. The compressibility of the mix containing high volume of EFB was relatively high, where the mix quickly recovered from the compressive deformation after compaction. These factors led to the low cohesive strength of the mix, and therefore, the specimens were not in shape after demoulding (1 day after casting).

3.3. Density

The cement content directly influenced the density of the specimen. The mixes 1:2.5 that had a higher cement content always gave a higher density than 1:3 (Table 6). High cement content (a) increased the cohesiveness of the fresh mix, allowing better quality of compaction, (b) created a stronger bond between sand and EFB fibres and (c) for the smaller particles, filled the void in the mix.

When EFB fibre content increased from 0% to 20%, the differences in density between mixes 1:2.5 and 1:3 reduced from 12% to 2% (Table 6). This could be attributed to the low cohesive strength of the fresh mixes. As the EFB fibre in the mix was ineffectively reframed from compressibility recovery after the compaction, more voids were created in the mix 1:3.

Table 6. Density of specimens with different EFB content at day 28

EFB content (%)	c/s ratios		Density ratio, $R_d = \frac{\rho_{E1}}{\rho_{E2}}$
	1:2.5	1:3	
0	1859	1654	1.12
10	1720	1610	1.07
15	1550	1497	1.04
20	1477	1450	1.02
25	1447	-	

The density of the specimen decreased with the increase of EFB fibre content (Fig. 5). EFB fibre was a cellular structure possessing many micro-pores and a great volume of void. For that, the increase of EFB fibre content increased the void in the mix [13].

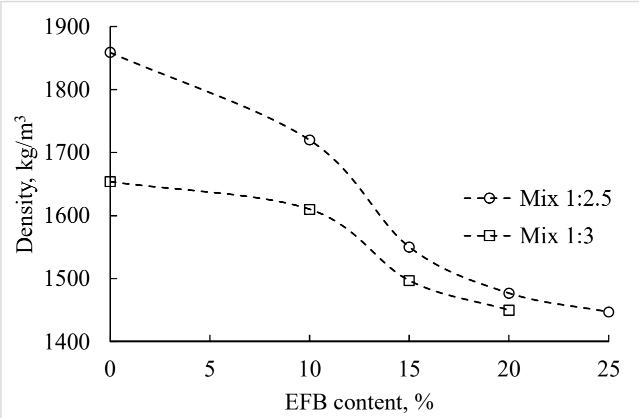


Fig. 5. Effects of EFB on density of the specimen

Also, EFB fibre was highly compressible, where the cellular structure tended to partially recover after removal of the compacting pressure. With the fibres randomly scattered in the mix, the compactness of the specimen was affected. This, to some extent, reduced the density of the specimen.

3.4. Water absorption

The water absorption of the specimen increased by approximately 24% and 27% as EFB content increased from 0% to 20% for the mixes 1:2.5 and 1:3 respectively (Fig. 6). This was due to the hydrophilic nature and low density of EFB fibre [4]. The micro-pores and voids in the cellular structure of EFB fibre encouraged the capillary suction of water and provided rooms to store water.

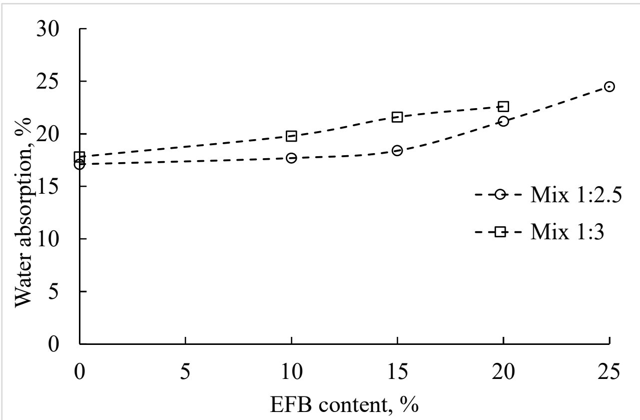


Fig. 6. Effects of EFB on water absorption of the specimen

4. Feasibility evaluation

To determine the feasibility of adopting EFB fibre in cement bricks, the specimens were evaluated based on some criteria related to industrial applications, as follows:

a. Criteria 1: The bricks should be of standardized size within tolerable limits for the workability purpose and as a part of the quality control. The size limits as defined by BS 3921:1985 [12] was about ±6%, as computed in Table 7. Thus, the volume ratio, R_v, should be less than 0.06, as expressed in Eq. 4.

$$R_v = \left|\frac{V_m - V_w}{V_w}\right| \leq 0.06 \quad (4)$$

where V_m = volume of the specimen based on the measured dimensions, mm^3

V_w = volume of the standard size, mm^3

b. Criteria 2: Although brick is typically non-loadbearing, it should have a compressive strength of at least 7 N/mm^2 [12] to carry the stacking loads and for handling purposes. With that, the strength ratio, R_s, should be at least 1.0 (Eq. 5).

$$R_s = \frac{\sigma_i}{\sigma_{req}} \geq 1.0 \quad (5)$$

where σ_i = compressive strength of the specimen, N/mm^2
σ_{req} = minimum compressive strength of brick, 7 N/mm^2

c. Criteria 3: For easy handling, the brick should be lightweight with a density not exceeding 1680 kg/m^3 [14]. Therefore, the density ratio, R_d, should be less than 1.0 (Eq. 6).

$$R_d = \frac{\rho_i}{\rho_{req}} \leq 1.0 \quad (6)$$

where ρ_i = density of the specimen, kg/m^3
ρ_{req} = maximum density for a lightweight brick, 1680 kg/m^3

d. Criteria 4: The water absorption property of brick tends to extract the water from the mortar and plaster. Excessive extraction of water would affect the bond strength and aesthetic appeal. The water absorption rate should not exceed 20% [15], and hence, the absorption ratio, R_a, should be less than 0.2 (Eq. 7).

$$R_a = \frac{WA}{100} \leq 0.2 \quad (7)$$

where WA = water absorption of the specimen (%)

Table 7. Limits of brick size by BS3921

Dimension	Standard size	Measurement of 24 bricks		Measurement of 1 brick*[1]	
		Min	Max	Min	Max
Length, l (mm)	215	5085	5235	211.8	218.1
Width, b (mm)	102.5	2415	2505	100.6	104.3
Height, h (mm)	65	1515	1605	63.1	66.8
Volume, V (mm^3)*[2]	1432438			1344477	1519555

**Note:* [1]*The measurements were computed from the measurement limits for 24 bricks*
[2]*Volume of brick,* $V = l \times b \times h$
[3]*the ratios of volume against the standard size,* V_{max}/V *and* V_{min}/V*, were 1.06 and 0.94, respectively.*

The specimens were considered applicable in construction when all four criteria (i.e. C1, C2, C3 and C4) were fulfilled, as evaluated in Table 8.

From Table 8, the followings are observed:

a. All specimens fulfilled Criteria 1 with the variation of volume not exceeding 6%. However, it is noted that the height, h, of the specimen E1-20 and E1-25 was 67.0 mm (Table 3) had slightly exceeded the limit (66.8 mm) as computed in Table 7.
b. The specimens achieved the required strength (Criteria 2) with the EFB content not exceeding 15% and 10% of the mixes 1:2.5 and 1:3 respectively.
c. The specimens were considered lightweight (Criteria 3) at a minimum EFB fibre content of 15% and 0% for the mixes 1:2.5 and 1:3 respectively.
d. To meet Criteria 4 on water absorption, EFB content should not exceed 15% and 10% for the mixes 1:2.5 and 1:3 respectively.

Table 8. Feasibility evaluation of the test specimen

Criteria	C1		C2		C3		C4		Remarks*[2]
Specimen	Volume ratio, R_v		Strength ratio, R_s		Density ratio, R_d		Water absorption ratio, R_a		
	Eq. 4	≤ 0.06	Eq. 5	≥ 1.0	Eq. 6	≤ 1.0	Eq. 7	≤ 0.2	A / NA
C1	0.00	√	1.66	√	1.11	X	0.17	√	NA
E1-10	0.00	√	1.33	√	1.02	X	0.18	√	NA
E1-15	0.02	√	1.07	√	0.92	√	0.18	√	A
E1-20	0.04	√	0.83	X	0.88	√	0.21	X	NA
E1-25	0.04	√	0.69	X	0.86	√	0.25	X	NA
C2	0.00	√	1.37	√	0.98	√	0.18	√	A
E2-10	0.00	√	1.13	√	0.96	√	0.20	√	A
E2-15	0.00	√	0.97	X	0.89	√	0.22	X	NA
E2-20	0.03	√	0.79	X	0.86	√	0.23	X	NA
E2-25*[3]	-	X	-	X	-	X	-	X	NA

*Note: [1]√ - the requirement was fulfilled, X - the requirement was not fulfilled,
[2]A – Applicable (all criteria fulfilled), NA – Not Applicable (at least 1 criteria not fulfilled)
[3]No result was obtained.

Based on these observations, the strength ratio, R_s, and the water absorption ratio, R_a, were two key criteria governing the applicability of the specimens in construction. If the lightweight property (Criteria 3) was optional, EFB fibre may replace the sand at a maximum of 15% and 10% for the mixes of 1:2.5 and 1:3 respectively.

5. Conclusion

In this study, EFB fibre was used to partially replace the sand used to produce cement bricks. EFB fibre was found detrimental to the overall performance of the specimen. For the porous cellulous structure, EFB reduced the density and increase the water absorption of the specimens. Due to low compressive resistance and poor bond with the cement matrix, EFB fibre reduced the compressive strength of the specimen. A 25% EFB fibre in the mix 1:2.5 reduced 59% of compressive strength and increase 43% of water absorption of the specimen, which were unfavourable for the construction industry.

Based on the evaluation criteria in the aspects of size, strength, density and water absorptions of the specimens, EFB fibre content should not exceed 15% and 10% of sand replacement in the mixes of 1:2.5 and 1:3 respectively.

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