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Effects of Adding Silica Fume and Empty Fruit Bunch to the Mix of Cement Brick

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ABSTRACT

Silica fume (SF) and palm oil empty fruit bunch (EFB) are the by-products of the ferroalloy smelting industry and oil palm plantation, which require proper disposal to minimize the environmental impacts. To consume the by-products, the feasibility of utilizing SF and EFB to fabricate bricks was studied. Limited studies were adopting EFB as the natural fibres in bricks and its proportion barely exceeded 5%. With the enhancement of SF, EFB content in the mix could be increased. In this study, 336 specimens were produced in the cement-to-sand (c/s) ratios of 1:2.5 and 1:3, where SF replaced 10% to 15% cement in the mix by weight while EFB substituted 20% to 25% sand by volume. The specimens were tested for the compressive strength, density, and water absorption properties. SF was found to strengthen the mix, while EFB reduced the compressive strength and increased the water absorption capacity of the brick. Based on the evaluation results, the mix containing less than 10% SF and 20% EFB content was applicable for non-load-bearing brick.

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1. INTRODUCTION

Palm oil empty fruit bunch (EFB) is a biomass waste from the palm oil industry. It constitutes about 1/4 of the weight of the fresh fruit bunch for the extraction of palm oil (Dalimin, 1995; Harsono et al., 2016). As one of the major oil palm producer in the world producing about 19.9 million tonnes of crude palm oil in 2019 (Malaysian Palm Oil Board, 2020), EFB is abundantly produced in Malaysia.

EFB can be used as biofuel, organic fertilizer, animal fodder, growth media for fungi and plants, as well as mat-making materials (Abdullah et al., 2011; Ismail & Yaacob, 2011; Chang, 2014; (Harsono et al., 2016). However, these applications only constitute some percentage of the EFB produced, whereas the rest is left rotting (Harsono et al., 2016), which attracts pests and fouling (Ismail & Yaacob, 2011); or worst, illegally burned, which pollutes the environment (Kadir et al., 2017).

EFB was though applicable for the fabrication of bricks and blocks (Kolop et al., 2008; Ismail & Yaacob, 2011; Danso et al., 2015; Kadir et al., 2017a; Raj & Gomez, 2017; Ling et al., 2019). This could further consume EFB as brick is one of the most widely used materials in the construction industry (Kumar et al., 2017), which constitute about 25% material of a typical building structure (Gawatre & Vairagade, 2012).

However, excessive EFB would affect the strength of brick (Ling et al., 2019). Its content in laterite and fired clay bricks was recommended as 3% and 5% respectively (Ismail & Yaacob, 2011; Kadir et al., 2017a; Kadir et al., 2017b). EFB content in cement brick exceeding 15% was not applicable for construction (Ling et al., 2019). Presumably, the cementitious binder can strengthen the mix more effectively, allowing cement brick to accommodate more EFB than the other types of brick.

This study intended to further increase the EFB content in the cement bricks by taking the advantage of the pozzolanic action triggered by silica fume, which was a by-product of the ferroalloy smelting industry.

With that, SF and EFB were used to partially replace the cement and sand used in the cement bricks respectively. The mixes were evaluated in terms of compressive strength, density, and water absorption to determine the feasibility of the building material.

2. MATERIALS AND METHODS

2.1. Materials

Table 1. Physical properties of ordinary Portland cement

Parameter	Specifications
Early strength (2 days)	18.0 N/mm^2
Standard Strength (28 days)	50.0 N/mm^2
Initial setting time	160 min
Expansion (Le Chatelier)	0.5 mm

Ordinary Portland cement (strength class 42.5 N/mm^2) conforming to MS EN 197-1:2014 was used. The physical properties and chemical composition are listed in **Tables 1** and **2**, respectively.

Table 2. Chemical composition of cement and silica fume (%)

Chemical Composition	Cement	Silica fume
Total Silica, SiO_2	19.34	85.45
Aluminium oxide, Al_2O_3	5.20	-
Ferric oxide, Fe_2O_3	3.41	-
Free Calcium Oxide, CaO	64.75	0.16
Magnesium Oxide, MgO	1.44	4.43
Sulfate, SiO_3	2.85	0.69
Potassium Oxide, K_2O	0.47	0.15
Sodium Oxide, Na_2O	0.10	0.14
Chloride, Cl^-	-	0.02
Total Alkalinity, Na_2O + 0.658 K_2O	-	0.24
Free Silicon	-	0.03
Loss on Ignition*	3.42	1.91

**Note: Ignition time: 1 hour*

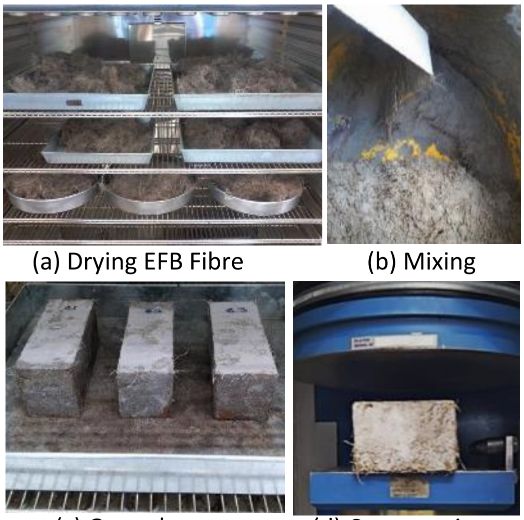
The chemical composition of the silica fume used is listed in **Table 2**. It conformed to ASTM C 1240-04 and CSA A23.5-M98 for cementitious mixtures, which had (a) at least 85% SiO_2, (b) less than 6% loss on ignition, and (c) more than 15 m^2/g specific surface area (18.2055 ± 0.3446 m^2/g).

EFB fibres were cut into approximate lengths of 40 mm and oven-dried in an electric oven at 100°C to 115°C temperature for 24 hours. The preparation and testing of specimens are shown in **Figure 1**. The physical properties of EFB are given in **Table 3**.

Table 3. Properties of EFB fibres

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

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



(a) Drying EFB Fibre (b) Mixing

(c) Oven dry (d) Compressive

Figure 1. Preparation and testing of the specimens.

2.2. Mix proportion

Mix proportions of the specimens are provided in **Table 4**. Two series of mixes with the cement-to-sand (c/s) ratio of 1:2.5 and 1:3 with the water-to-binder (w/b) ratio of 0.5, based on the typical range of 1:2 to 1:4 c/s ratio and w/b ratio of 0.5 maximum (Bengtsson and Whitaker, 1988). The mixes were classified into four categories, which were the mixes (a) without EFB and SF, (b) with EFB only, (c) with SF only, and (d) with EFB and SF, where SF replaced 10% to 15% of cement by mass and EFB substituted 20% to 25% sand by volume.

2.3. Test methods

Bricks of 215 mm x 102.5 mm x 65 mm were prepared in steel molds. All specimens were uniformly compacted by 25 strokes of rod compactor in 3 layers, cured indoors under a waterproof plastic sheet at the room temperature of 30 ± 5oC with a relative humidity of 60%-80% for one day and then, de-molded and submerged in water.

At the ages of 3, 7 and 28 days, the compressive strengths of the specimens were tested. On day 28, the dimension, density and water absorption of the specimens were also determined. Average values of 3 specimens were taken for all the results, and thus, each mix proportion comprised 12 specimens, which gave a total of 336 specimens.

Table 4. Mix proportion and total specimens tested

Mix	c/s ratio	SF content (%)	EFB content (%)	Units
C1-1			0	12
C1-2		0	20	12
C1-3			25	12
C1-4		10	0	12
C1-5		15		12
S1-1		10		12
S1-2	1:2.5	12.5	20	12
S1-3		15		12
S1-4		10		12
S1-5		12.5	22.5	12
S1-6		15		12
S1-7		10		12
S1-8		12.5	25	12
S1-9		15		12
C2-1			0	12
C2-2		0	20	12
C2-3			25	12
C2-4		10	0	12
C2-5		15		12
S2-1		10		12
S2-2	1:3.0	12.5	20	12
S2-3		15		12
S2-4		10		12
S2-5		12.5	22.5	12
S2-6		15		12
S2-7		10		12
S2-8		12.5	25	12
S2-9		15		12
			Total	336

3. RESULTS AND DISCUSSION

3.1. Materials

The specimen sizes as measured by Vernier caliper on day 28 are provided in **Table 5**. The differences from the working size of 215 mm x 102.5 mm x 65 mm were assumed due to the expansion that occurred after compaction and during the hardening process of the mixes.

Table 5. Mix proportion and total specimens tested.

Mix	Length, *l* (mm)	Width, *b* (mm)	Height, *h* (mm)	Volume, *V* (mm^3)
C1-1	215.0	102.0	65.0	1425450
C1-2	216.0	102.5	67.0	1483380
C1-3	216.5	103.0	67.0	1494067
C1-4	215.0	102.3	65.0	1429643
C1-5	215.0	102.0	65.0	1425450
S1-1	215.2	103.1	66.1	1466569
S1-2	215.0	102.5	66.5	1465494
S1-3	215.1	102.5	66.0	1455152
S1-4	215.3	103.0	66.3	1470262
S1-5	215.2	103.4	66.8	1486412
S1-6	215.3	102.8	66.7	1476260
S1-7	215.6	102.7	66.2	1465808
S1-8	215.4	102.5	66.7	1472636
S1-9	215.4	102.5	66.7	1472636
C2-1	215.0	102.0	65.0	1425450
C2-2	216.0	103.0	66.5	1479492
C2-3*	-	-	-	-
C2-4	215.0	102.1	65.0	1426848
C2-5	215.0	102.2	65.0	1428245
S2-1	215.0	102.5	66.1	1456679
S2-2	215.2	102.5	66.7	1471269
S2-3	215.4	102.5	66.4	1466012
S2-4	215.5	102.5	66.5	1468902
S2-5	215.6	102.5	66.1	1460744
S2-6	215.4	103.0	66.7	1479820
S2-7	215.5	103.0	66.7	1480507
S2-8	215.6	103.0	66.5	1476752
S2-9	215.5	103.0	66.6	1478287

**Note: The specimens collapsed during demolding, thus the dimension was not measured.*

In terms of the degree of expansion (in millimeter), the followings were observed:

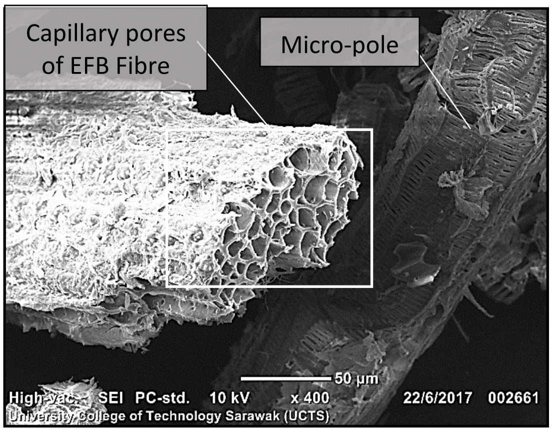
a. The degree of expansion increased with the increase of EFB content in the mixes. Among the mixes of 1:3 c/s ratio, specimens S2-7, 8, and 9 having 25% EFB content generally expanded more than specimens S2-1, 2, and 3 with 20% EFB content (**Table 5**). A similar response was also observed in the mixes 1:2.5 c/s ratio between the specimen groups S1-7 to 9, and specimens S1-1 to 3.

b. The heights, h, of the specimens increased the most as compared with its length, l, and width, b. The maximum expansions of height, length, and width of all specimens were 1.8 mm, 0.6 mm, and 0.9 mm respectively.

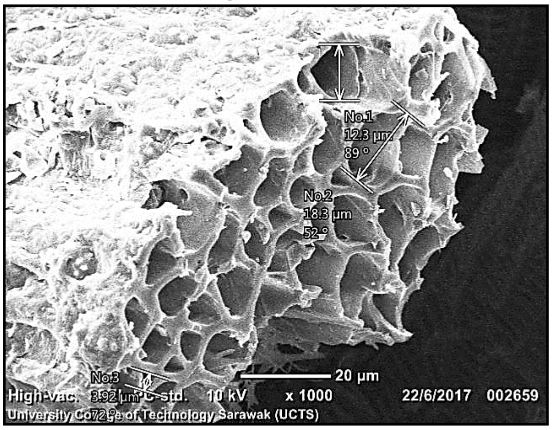
c. Among the specimens with the same SF and EFB contents, the mixes of 1:3 c/s ratio generally expanded more than 1:2.5.

These phenomena were mainly due to the compressibility characteristics of EFB fibre, which was made of a bunch of ligneous-like micro-fibres that formed the cellulose structure with lots of voids, as given in **Figure 2** (Ling et al., 2019).

Under compacting pressure, EFB fibres were compressed to have less void within their cellulose structure. However, as the compacting pressure was removed, the fibre tended to partially recover from the compressive deformation. This caused the fresh mix to expand vertically after the removal of the compacting pressure. It later marginally enlarged in all direction after demolding (**Figure 3**).



(a) Magnification x400



(b) Magnification x1000

Figure 2. Microstructure of EFB fibre sample

SF seemed to affect the compressibility characteristics of EFB fibre. The existence of SF in the mixed had limited the expansion of the mixes containing EFB fibre. For example, among the mixes containing 25% EFB fibre, the specimen without SF (specimen C1-3) expanded more than those with SF (specimens S1-7, 8, and 9). This phenomenon also happened in the mixes with 20% EFB content regardless of the c/s ratios of 1:2.5 and 1:3.

This could be due to the filling of voids in the cellulose structure of EFB fibre by the fine SF particles. The particle size of SF was generally smaller than 1 µm with an average diameter of 0.1 to 0.2 µm (ACI Committee 234, 2006), and the poles in EFB fibres could reach 18.3 µm as measured in **Figure 2(b)**.

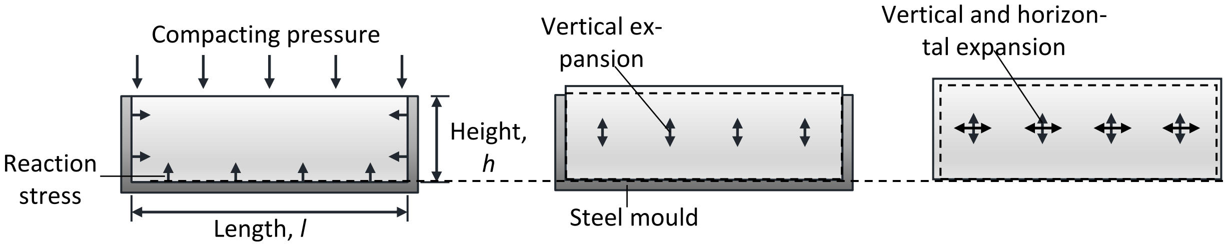
This had affected EFB fibre in terms of (a) the flexibility to deform, (b) the degree of compressibility deformation under compacting pressure and (c) the rate of recovery from compressive deformation after removal of the compacting pressure.

3.2. Compressive strength

The compressive strengths of the mixes at the ages of 3, 7, and 28 days are given in **Table 6**, as computed from the ultimate compressive force, P, and the contact surface area, A, of the specimens (Equation (1)).

$$\sigma_i = \frac{P}{A} \quad (1)$$

The compressive strengths of the mixes increased with the age, reaching about 1/3, 2/3 and full strength on days 3, 7, and 28 respectively. The strength developed at a typical rate of a cementitious mix, which implied an acceptable quality of the cementitious binders (i.e. cement and SF) used in the mixes.



(a) During compaction (b) After compaction (c) After demolding

Figure 3. Compressibility recovery of specimen after compaction and demolding.

From **Table 6**, the mixes of 1:2.5 c/s ratio were always stronger than 1:3. The mixes had a higher content of cementitious binder that strengthened the bond between the constituents (i.e. sand and EFB fibre).

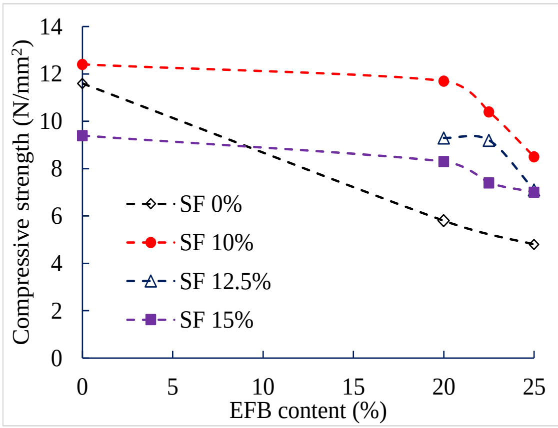
Table 6. Test results

Mix	Compressive Strength (N/mm^2)			Density (kg/m^3)	Water Absorption (%)
	Day 3	Day 7	Day 28	Day 28	Day 28
C1-1	3.3	6.6	11.6	1654	18.1
C1-2	2.2	4.8	5.8	1477	21.2
C1-3	1.8	3.2	4.8	1447	24.5
C1-4	4.1	8.2	12.4	1764	17.5
C1-5	3.2	6.2	9.4	1567	16.6
S1-1	4.1	8.0	11.7	1574	17.2
S1-2	3.6	6.2	9.3	1571	16.2
S1-3	3.1	5.4	8.3	1566	15.6
S1-4	4.1	6.8	10.4	1563	17.7
S1-5	3.4	5.4	9.2	1531	16.6
S1-6	3.2	5.2	7.4	1529	16.6
S1-7	3.4	5.8	8.5	1538	18.0
S1-8	2.9	5.1	7.1	1520	17.6
S1-9	2.4	4.8	7.0	1512	17.0
C2-1	3.0	6.2	9.6	1601	22.8
C2-2	1.7	3.6	5.5	1450	22.6
C2-3	-	-	-	-	-
C2-4	3.8	7.5	11.3	1600	21.0
C2-5	3.0	5.9	8.9	1387	19.7
S2-1	3.7	6.0	8.1	1562	19.0
S2-2	2.7	4.3	6.4	1532	18.0
S2-3	2.2	3.7	5.9	1526	17.8
S2-4	3.3	5.1	7.9	1510	20.8
S2-5	2.1	3.5	5.4	1509	19.5
S2-6	1.7	2.6	4.0	1483	18.5
S2-7	1.9	2.9	5.5	1479	21.9
S2-8	1.3	2.3	4.1	1461	20.8
S2-9	1.0	2.0	3.7	1453	20.4

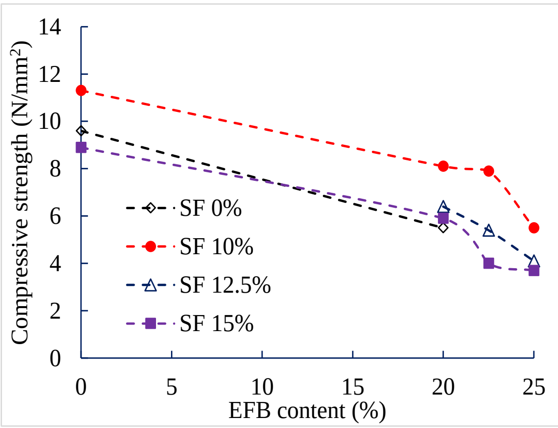
**Note: The mix C2-3 collapsed during demolding, and thus the specimens were not tested.*

EFB fibre affected the compressive strength of the mixes. The strength reduced with the increase of EFB content, as displayed in **Figure 4**. In the absence of SF, the reduction in strength was more pronounced, which was about proportional to the increase of EFB content. These responses can be seen from the almost-straight curve of 0% SF in **Figure 4(a)**, the negative gradient of which was the greatest of all.

This was mainly due to the low compressive strength of EFB fibre as compared with the sand it replaced (Ling et al., 2019). EFB fibre appeared as a cellulose structure made of lots of micro-fibre that were susceptible to deformation and fracture. This characteristic, to some extent, affected the bond of EFB fibre with the cement matrix, where the cellulose structure may regionally facture or tear off under excessive stress.



(a) Mixes 1:2.5



(b) Mixes 1:3

Figure 4. Effects of EFB content on compressive strength of specimens.

SF had enhanced the compressive strength of the mixes. This was demonstrated by specimens C1-4 and C2-4 containing 10% SF and 0% EFB as compared with specimens C1-1 and C2-1 without SF and EFB. The pozzolanic effects of SF had strengthened the bond between the cement pates and the sand (ACI Committee 234, 2006).

However, for a positive effect on the compressive strength, SF content in the mix should not exceed 10%. The mixes with 12.5% and 15% SF contents gave lower compressive strengths than those with 10% SF content regardless of the amount of EFB in the mixes.

SF had reduced the rate of strength reduction caused by EFB fibre. This was observed from a milder negative gradient of the curves representing the relationship between the compressive strength and EFB content in **Figure 3**. In the absence of SF, 25% EFB content reduced about 59% strength of the mixes of 1:2.5 c/s ratio, as observed from specimens C1-1 and C1-3 (**Table 6**). However, with 10% SF, the strength reduction reduced to 27% only, as given by specimens S1-7 and C1-1.

3.3. Density and water absorption

The density, ρ, and water absorption, WA, of the specimens were determined based on the mass of the specimens under different conditions, as expressed in Equations (2) and (3) and given in **Table 6**.

$$\rho = \frac{w_d}{w_s - w_i} \times 100\% \quad (2)$$

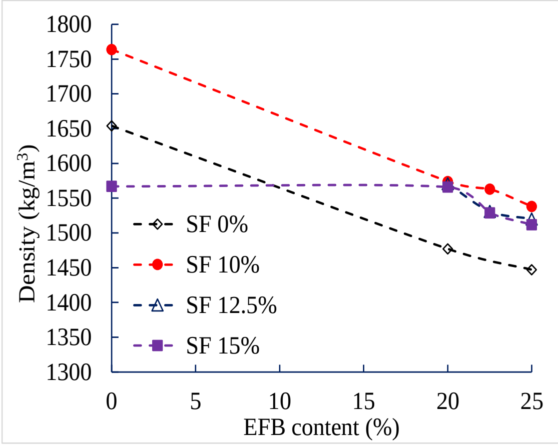
$$WA = \frac{w_s - w_d}{w_d} \times 100\% \quad (3)$$

where:

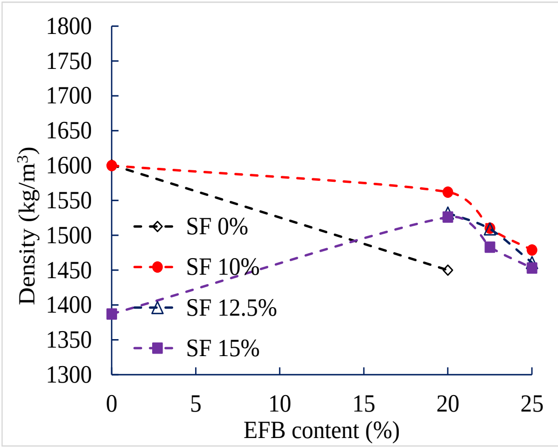
W_i = mass of the immersed specimen, kg

W_s = mass of the saturated specimen, kg

W_d = mass of the oven-dry specimen, kg



(a) Mixes 1:2.5



(b) Mixes 1:3

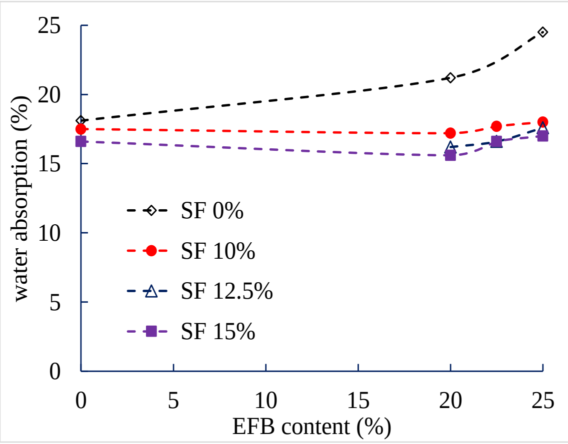
Figure 5. Effects of EFB on density of specimens.

In terms of the density, the followings were observed: (see **Figure 5**)

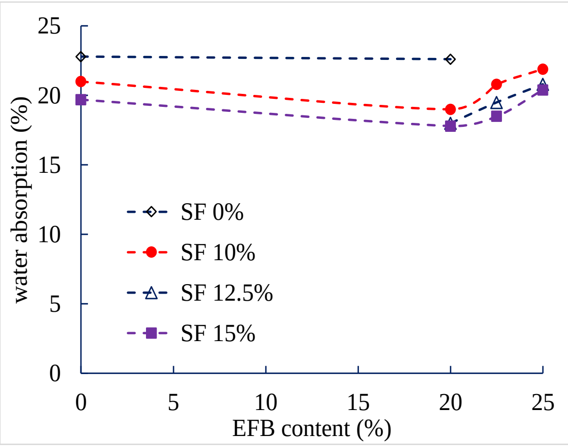
a. The mixes with a higher cement content (c/s ratio = 1:2.5) generally had a higher density than those with lower cement content (c/s ratio = 1:3). This was attributed to several factors, namely (i) the small particles of cementitious binders (i.e. cement and SF) that filled the voids in EFB fibre and the mix, (ii) these binders that made the fresh mixes cohesive for better compaction, and (iii) a higher cementitious binder content in the mixes strengthened the bond with the constituents (i.e. sand and EFB fibre).

b. EFB fibre reduced the density of the specimens. The mix with 25% EFB and 0% SF had a 12.5% lower density than a normal cement brick, as observed through the comparisons of specimens C1-3 and S1-7. The cellulose structure of EFB fibre created additional voids in the mixes.

c. SF increased the density of the specimens. The mixes containing 10% to 15% SF generally had a higher density than those without SF. This could be due to the filling of voids in the mixes by the fine SF particles.



(a) Mixes 1:2.5



(b) Mixes 1:3

Figure 6. Effects of EFB content on water absorption of specimens.

In terms of water absorption, the followings were observed: (see **Figure 6**)

a. The mixes of 1:2.5 c/s ratio generally demonstrate a higher water absorption capacity than 1:3. These specimens were denser and contained fewer voids for the penetration of water.

b. The water absorption increased with EFB content. Beyond 20% EFB content, the water absorption capacity increased almost proportionally to EFB content. The pores of EFB fibre encouraged the capillary suction of water and provided rooms to store water.

c. SF reduced the water absorption capacity of the mixes. The mixes with 15% SF content had a lower water absorption capacity than 10% SF.

4. FEASIBILITY EVALUATION

To determine the feasibility of the mixes for the applications in the construction industry, the specimens were evaluated based on the following criteria:

a. Criteria 1: The specimens should not endure excessive expansion after casting. As a part of the quality control, the size of the specimens should be within the tolerable limits defined by BS 3921:1985, which is equivalent to ±6% of the standard volume (**Table 7**). With that, the volume ratio, Rv, as computed in Equation (4) should not exceed 0.06.

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

Where

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

V_w = volume of the specimen of the standard size, mm^3

b. Criteria 2: As a non-loadbearing brick, the specimens should have a minimum compressive strength of 7 N/mm^2 (BS3921:1985, 1985). This is meant to carry the staking weight of the bricks and for handling and mobilization purposes. Thus, the strength ratio, Rs, should be at least 1.0 (Equation (5)).

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

Table 7. Limits of brick size as per 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.*

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 specimens are preferably lightweight, not exceeding 1680 kg/m^3 (ASTM C1634-11). Therefore, the density ratio, Rd, should be less than and equal to 1.0 (Equation (6)).

$$R_d = \frac{\rho_i}{\rho_{req}} \leq 1.0 \tag{6}$$

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: High water absorption rate exceeding 20% is not favourable (IS 1077: 1992), as it tends to extract the water from the mortar and plaster, as well as encourages efflorescence. This would affect the bond strength and aesthetic appeal. Hence, the water absorption ratio, Ra, should not be greater than 0.2 (Equation (7)).

$$R_a = \frac{WA}{100} \leq 0.2 \tag{7}$$

where WA = water absorption of the specimen (%)

Table 8 presents the feasibility evaluation of the specimens. For the specimens to be considered applicable for construction, all four criteria need to be fulfilled.

The evaluation outcomes are summarized as follows (**Table 8**):

a. The mixes that constituted solely sand and cement in the c/s ratio of 1:2.5 were considered applicable, but the mix 1:3 c/s ratio was not applicable due to excessive water absorption (Ra = 0.23), as demonstrated by specimens C1-1 and C2-1 respectively.
b. The mixes with EFB content exceeding 20% were not applicable due to inadequate strength (Rs < 1.0) and excessive water absorption (Ra > 0.2), as observed from specimens C1-2, C1-3, C2-2 and C2-3.
c. The mixes with 10% SF content (specimens C1-4 and C2-4) in the c/s ratio of 1:2.5 and 1:3 did not fulfil criteria 3 and 4. The mix C1-4 was not lightweight and C2-4 had an excessive water absorption rate.
d. The mixes with 10% to 15% SF content and 20% to 25% EFB content were considered applicable if the c/s ratio was 1:2.5. For those with a 1:3 c/s ratio, only the mix with 10% SF and 20% EFB fibre fulfilled all four evaluation criteria.

Based on the valuation results, the following principles of the applications of the mixes are outlined:

a. If the strength of the mix is the sole and utmost concern, the mix with 10% SF and 0% EFB content may be used, as it gave the highest strength of all the mixes in this study.

b. For general application in construction, the mix with less than 10% SF and 20% EFB content was recommended. 25% of EFB content may be applied to the mixes with the c/s ratio not exceeding 1:2.5. SF content exceeding 10% is not recommended due to the concern of the potential leaching of unreacted SF from the mix.

Table 8. Feasibility evaluation of the specimens for industrial application

Criteria	C1		C2		C3		C4		
Mix	**Volume ratio, R_v**		**Strength ratio, R_s**		**Density ratio, R_d**		**Water absorption ratio, R_a**		**Remarks**
	Eq. 4	≤ 0.06	**Eq. 5**	≥ 1.0	**Eq. 6**	≤ 1.0	**Eq. 7**	≤ 0.2	**A / NA**
C1-1	0.00	√	1.66	√	0.98	√	0.18	√	A
C1-2	0.04	√	0.83	X	0.88	√	0.21	X	NA
C1-3	0.04	√	0.69	X	0.86	√	0.25	X	NA
C1-4	0.00	√	1.77	√	1.05	X	0.18	√	NA
C1-5	0.00	√	1.34	√	0.93	√	0.17	√	A
S1-1	0.02	√	1.67	√	0.94	√	0.17	√	A
S1-2	0.02	√	1.33	√	0.94	√	0.16	√	A
S1-3	0.02	√	1.19	√	0.93	√	0.16	√	A
S1-4	0.03	√	1.49	√	0.93	√	0.18	√	A
S1-5	0.04	√	1.31	√	0.91	√	0.17	√	A
S1-6	0.03	√	1.06	√	0.91	√	0.17	√	A
S1-7	0.02	√	1.21	√	0.92	√	0.18	√	A
S1-8	0.03	√	1.01	√	0.90	√	0.18	√	A
S1-9	0.03	√	1.00	√	0.90	√	0.17	√	A
C2-1	0.00	√	1.37	√	0.95	√	0.23	X	NA
C2-2	0.03	√	0.79	X	0.86	√	0.23	X	NA
C2-3	-	-	-	-	-	-	-	-	NA
C2-4	0.00	√	1.61	√	0.95	√	0.21	X	NA
C2-5	0.00	√	1.27	√	0.83	√	0.20	√	A
S2-1	0.02	√	1.16	√	0.93	√	0.19	√	A
S2-2	0.03	√	0.91	X	0.91	√	0.18	√	NA
S2-3	0.02	√	0.84	X	0.91	√	0.18	√	NA
S2-4	0.03	√	1.13	√	0.90	√	0.21	X	NA
S2-5	0.02	√	0.77	X	0.90	√	0.20	√	NA
S2-6	0.03	√	0.57	X	0.88	√	0.19	√	NA
S2-7	0.03	√	0.79	X	0.88	√	0.22	X	NA
S2-8	0.03	√	0.59	X	0.87	√	0.21	X	NA
S2-9	0.03	√	0.53	X	0.86	√	0.20	√	NA

**Note: A – Applicable (all four criteria fulfilled), NA – Not Applicable (at least one criteria not fulfilled)*

5. CONCLUSION

This paper presents the effects of EFB fibre and SF on the properties of cement bricks. Based on the experimental results, EFB fibre was detrimental to the overall performance of the brick specimens. It affected the workability of the fresh mixes, increased the degree of expansion of the mix after compaction, reduced the compressive strength, reduced the density and increased the water absorption rate of the specimens. Most of these effects, except for its lightweight property, were unfavourable for construction purposes.

SF can be used to strengthen the mix. It reduced the degree of strength reduction caused by EFB fibre. It also increased the density and decreased the water absorption capacity of the specimens. This was likely due to the filling of the voids in EFB fibre by the small SF particles.

As a non-loadbearing brick for the building structures, SF and EFB content in the mix was recommended not exceeding 10% and 20% respectively.

However, there are some drawbacks of the proposed mixes, particularly in terms of fire resistance and health hazard. Such brick may not be fire resistance due to the combustible characteristics of EFB fibre, and there could be leaching of unreacted SF out of the bricks which may lead to respiratory problems upon inhalation. EFB may also decay in brick particularly in tropical countries with hot climates and high humidities. These issues must be resolved before the actual application in the construction industry.

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REFERENCES

Abdullah, N., Sulaiman, F., & Gerhauser, H. (2011). Characterisation of oil palm empty fruit bunches for fuel application. *Journal of Physical Science*, *22*(1), 1–24.

ACI Committee 234. (2006). *Guide for the use of silica fume in concrete*.

Chang, S. H. (2014). An overview of empty fruit bunch from oil palm as feedstock for bio-oil production. *Biomass and Bioenergy*, *62*, 174–181. https://doi.org/10.1016/j.biombioe.2014.01.002.

Dalimin, M. N. (1995). Renewable energy update: Malaysia. *Renewable Energy*, *6*(4), 435–439. https://doi.org/10.1016/0960-1481(94)00070-M.

Danso, H., Martinson, D. B., Ali, M., & Williams, J. B. (2015). Physical, mechanical and durability properties of soil building blocks reinforced with natural fibres. *Construction and Building Materials*, *101*, 797–809. https://doi.org/10.1016/j.conbuildmat.2015.10.069.

Gawatre, D. W., & Vairagade, L. N. (2012). Strength characteristics of different types of bricks. *International Journal of Science and Research (IJSR)*, *3*, 2247–2252.

Harsono, H., Putra, A. S., Maryana, R., Rizaluddin, A. T., H'ng, Y. Y., Nakagawa-izumi, A., & Ohi, H. (2016). Preparation of dissolving pulp from oil palm empty fruit bunch by prehydrolysis soda-anthraquinone cooking method. *Journal of Wood Science*, *62*(1), 65–73. https://doi.org/10.1007/s10086-015-1526-3.

Ismail, S., & Yaacob, Z. (2011). Properties of laterite brick reinforced with oil palm empty fruit bunch fibres. *Pertanika Journal of Science & Technology*, *19*, 33–43.

Kadir, A. A., Sarani, N. A., Mokhtar, S. Z., & Abdullah, M. M. A. (2017a). Physical and mechanical properties by utilizing empty fruit bunch into fired clay brick. *AIP Conference Proceedings*, *1835*(1), 020012. https://doi.org/10.1063/1.4981834.

Kadir, A. A., Sarani, N. A., Zaman, N. N., & Abdullah, M. M. A. B. (2017b). Feasibility study on utilization of palm fibre waste into fired clay brick. *AIP Conference Proceedings*, *1835*(1), 020039. https://doi.org/10.1063/1.4981861.

Kolop, R., Im, H. W., & Eng, J. W. (2008). Properties of cement blocks containing high content of oil palm empthy fruit bunches (EFB) fibres. *Proceedings of the International Conference on Civil Engineering Practice (ICCE08)*.

Kumar, B. M. V., Ananthan, H., & Balaji, K. V. A. (2017). Experimental studies on cement stabilized masonry blocks prepared from brick powder, fine recycled concrete aggregate and pozzolanic materials. *Journal of Building Engineering*, *10*(10), 80–88. https://doi.org/10.1016/j.jobe.2017.02.007.

Ling, J. H., Lim, Y. T., Leong, W. K., Jusli, E., & Sia, H. T. (2019). Properties of cement brick with partial replacement of sand and cement with oil palm empty fruit bunches and silica fume. *Journal of the Civil Engineering Forum*, *5*(3), 289. https://doi.org/10.22146/jcef.47982.

Malaysian Palm Oil Board. (2020). *Economics and industry development division*. http://bepi.mpob.gov.my/index.php/en/.

Raj, A. N., & Gomez, C. P. (2017). Development of thermally efficient fibre based eco-friendly bricks. *Construction and Building Materials*, *133*, 275–284. https://doi.org/10.15680/IJIRSET.2017.0604131.