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Properties of Cement Brick with Partial Replacement of Sand and Cement with Oil Palm Empty Fruit Bunches and Silica Fume

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ABSTRACT Oil palm empty fruit bunches (EFB) and silica fume (SF) are the by-products of the oil palm plantation and the ferroalloy smelting industries, respectively. Improper disposal of these materials leads to negative implication to the environment. This study was carried out to investigate the potential application of EFB and SF in cement bricks. EFB fibre and SF replaced up to 25% of sand and cement in the mix, respectively, in several groups of specimens that distinguished the normal, EFB-, SF- and EFB-SF-cement bricks. The specimens were tested for the compressive strength, density and water absorption property. The results reveal that SF, at an optimum amount of 10% cement replacement, increased 10% of the strength of the cement brick. EFB fibre reduced the strength and density but increased water absorption property of the cement brick. For application in the construction industry, SF and EFB fibre contents should be kept within 10% and 20% respectively.

KEYWORDS Cement brick; Silica fume; Oil Palm Empty Fruit Bunches

1 INTRODUCTION

Malaysia is the second-largest oil palm producer in the world. It produced 19.5 and 11.2 million tonnes of Crude Palm Oil (CPO) and Fresh Fruit Bunches (FFB) in 2018, respectively (Malaysian Palm Oil Board, 2018a, 2018b). The oil palm empty fruit bunches (EFB) comprises 22% to 25% of the total weight of FFB. Aside from those used in direct combustion to generate electricity in palm oil mills (Awalludin *et al.*, 2015), EFB is mostly unused (Tanaka *et al.*, 2004) and left rotting at the plantation site (Harsono *et al.*, 2015). This leads to crucial environmental issues like attracting pests and fouling (Ismail and Yaacob, 2011).

On the other hand, Silica Fume (SF) is abundantly produced as a by-product of the ferroalloy industry in Malaysia. For the fine particles, massive inhalation of SF may incur adverse health effects (Davies, 1974; Jahr, 1980; Merget *et al.*, 2002). As a Scheduled Waste identified by the Department of Environment Malaysia (DOE), SF is prohibited from direct disposal into the environment. It can only be disposal at sites approved by the DOE.

For the pozzolanic characteristic (Nili, Ehsani and Shabani, 2010; Ajay and Rajeev, 2012; Baid and Bhole, 2013; Hussain and Sastry, 2014; Shitole and Mathapati, 2014), SF were used to partially substitute the cement in concrete and enhance its compressive strength and durability (Parhizkar, Ramezanianpour and Hillemeier, 2002; ACI Committee 234:2006, 2006; Rahmani and Ramzanianpour, 2008; Sharma, Khatri and Kanoungo, 2014; Ramezanianpour, Rezaei and Savoj, 2015). EFB was used to partially replace the sand in bricks and blocks to reduce their weight and density (Kolop, Haziman and Eng, 2008; Ismail and Yaacob, 2011; Aeslina Abdul Kadir *et al.*, 2017). This could resolve the disposal problems of the two materials while slowing down the consumption of sand and cement in the brick manufacturing industry.

In this study, EFB fibre and SF were used to partially replace the sand and cement used to produce cement bricks. The brick specimens were evaluated in terms of the compressive strength, density and water absorption properties to determine their feasibility for industrial application.

There were separated studies on the application of EFB fibre and SF in bricks, but none had used them together. SF is known to increase the compressive strength of brick (Hoque, Rahman and Islam, 2014; Thirugnanasambantham *et al.*, 2017), while EFB fibre reduces it (Kolop, Haziman and Eng, 2008). This study investigates if SF could be used to compensate for the strength loss caused by EFB fibre in cement bricks.

2 EXPERIMENTAL INVESTIGATION

2.1 Materials

Ordinary Portland cement used was conformed to MS EN 197-1:2014 for the strength class 42.5 N/mm^2. Its physical properties and chemical compositions are shown in Table 1 and Table 2, respectively.

Table 1. Physical properties of OPC used as given by the manufacturer

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

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

Chemical Composition	Cement	Silica fume
Total Silica, SiO_2	19.34	85.45
Aluminum 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*

SF used contained 85.45% SiO_2 (Table 2). The specific surface area was 18.2055 ± 0.3446 m^2/g. It met the requirements of ASTM C1240-04 and CSA A23.5-M98 as a cementitious mixture; SiO_2 ⩾85.0%, loss on ignition ⩽ 6.0%, SO_3 ⩽1.0%, and specific surface area ⩾15m^2/g.

River sand with at least 90% passing the 600 μm sieve was used. The water used for mixing and curing was the portable water treated by the local utility company, which was not detrimental to the durability of the bricks.

EFB fibres were ensured free from soil and dirt, separated and cut into an average length of 40 mm (Table 3). The fibres were oven-dried in an electric oven at the temperature of 100 - 115°C for 1 day. The tensile strength, Young's modulus and maximum elongation would be 24.9 - 550 MPa, 1.7 - 2.75 GPa and 4 - 18%, respectively (Mahjoub, Bin Mohamad Yatim and Mohd Sam, 2013).

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 from the same compaction method used to produce brick specimens in this study.*

2.2 Mix Proportion

The specimens were mixed in the cement-sand ratio of 1:2.5. EFB fibre and SF replaced 10% to 25% of sand and cement in the mixes, respectively, in the categories of (a) normal-, (b) EFB-, (c) SF- and (d) EFB and SF- cement bricks (Table 4).

Each mixture comprised 12 specimens; 9 specimens were tested for the compressive strength on days 3, 7 and 28 (3 specimens on each day), while another 3 for determining the density and water absorption on day 28. The number of specimens was doubled for the control mix (C-0-0). The average results were taken and presented in Table 4.

Table 4. Number of specimens with respect to each mix proportion

Mix	Silica Fume Content (%)	Empty Fruit Bunch Content (%)	No. of specimens
C-0-0	0	0	24
S-10-0	10	0	12
S-15-0	15	0	12
S-20-0	20	0	12
S-25-0	25	0	12
E-0-10	0	10	12
E-0-15	0	15	12
E-0-20	0	20	12
E-0-25	0	25	12
SE-10-20	10	20	12
SE-12.5-20	12.5	20	12
SE-15-20	15	20	12
SE-10-22.5	10	22.5	12
SE-12.5-22.5	12.5	22.5	12
SE-15-22.5	15	22.5	12
SE-10-25	10	25	12
SE-12.5-25	12.5	25	12
SE-15-25	15	25	12
		Total	228

*Note: *Ignition time: 1 hour*

2.3 Test Procedures and Conditions

Brick specimens, in the size of 215 mm x 102.5 mm x 65 mm, were cast in a steel mould (Figure 1). The specimens were mixed, cast and tested in accordance with the procedure stated by British Standards (BS EN 12390-2:2000, 2000; BS EN 206:2013:, 2013) in the temperature and relative humidity of 30 ± 5°C and 60% - 80% respectively. The mix was compacted by 25 strokes of rod compacter in 3 layers. The specimens were de-moulded 1 day after casting and were submerged in water for curing.

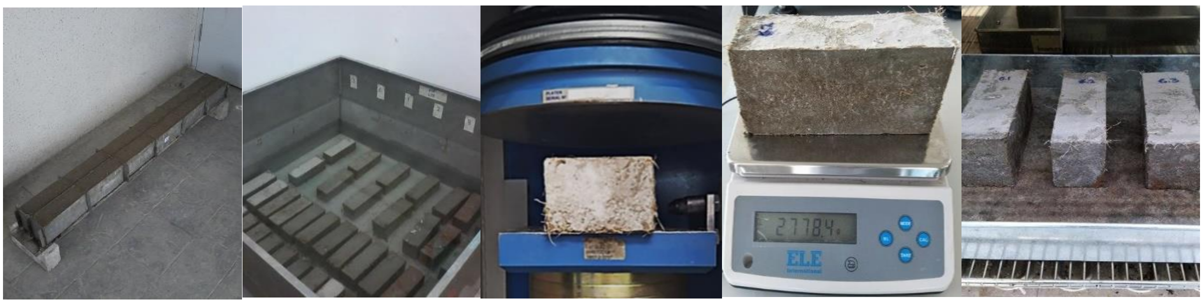
The size of the specimens was measured to be within limits defined by BS 3921:1985 (BS 3921:1985, 1985) (Table 5). Thus, the dimension was considered acceptable.

Table 5. Limits of size for bricks

Work size (mm)	Measurement of 24 bricks (mm)		Measurement of 1 brick* (mm)	
	Min	Max	Min	Max
215	5085	5235	211.8	218.1
102.5	2415	2505	100.6	104.3
65	1515	1605	63.1	66.8

*Note: *Ignition time: 1 hour*

(a) Silica Fume (b) Drying EFB (c) Mixing (d) Compacting



(e) Fresh mix air dried for 24 hrs (f) Curing for 28 days (g) Compressive test (h) Weighting the specimen (i) Oven-dry the specimens

Figure 1. Preparation and testing of the brick specimens

The specimens were tested by a compression machine and weighted by an electronic balance (Brand: ELE International, Capacity: 3000 kN and 30 kg, respectively) for the compressive strength, f_c, density, ρ, and water absorption, *WA*. The results were computed using Equations 1 to 3 (ASTM International, 2011a).

$$f_c = \frac{P_u}{A} \tag{1}$$

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

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

where: P_u = maximum compressive load, N
A = area of the specimen, mm^2
W_i = weight of the immersed sample, kg
W_s = weight of the saturated sample, kg
W_d = weight of the oven-dry sample, kg

3 RESULTS AND DISCUSSION

3.1 Conformability to Requirements

Table 6 outlines the test results of each mix proportion. The compressive strength on day 28, density and water absorption ranged from $4.8 N/mm^2$ to $12.4 N/mm^2$, 1447 kg/m^3 to 1764 kg/m^3 and 14.8% to 24.5%, respectively.

The test results are evaluated based on the following considerations:

a. The brick should be able to carry some loads, including its own weight. Thus, f_c should be at least 7 N/mm^2 (BS 3921:1985, 1985)
b. Lightweight brick is preferred for easy handling during construction. Thus, ρ should not exceed 1680 kg/m^3 (ASTM International, 2011b).
c. Excessive extraction of the moisture from the mortar plaster can affect its bonding strength and aesthetic appeal. Hence, WA should not exceed 20% (Bureau of Indian Standards, 1992).

Table 6. Chemical composition of cement and micro-silica (%)

Mix	Test Results					Evaluating Criteria*[1]		
	Compressive Strength, f_c (N/mm^2)			Density, ρ (kg/m^3)	Water Absorption, WA (%)	Strength	Density	Water Absorption
	Day 3	Day 7	Day 28	Day 28	Day 28	$f_c \geq 7 N/mm^2$	$\rho \leq 1680 kg/m^3$	$WA \leq 20\%$
C-0-0	3.5	7.0	11.3	1654	18.1	√	√	√
S-10-0	4.1	8.2	12.4	1764	17.5	√	X	√
S-15-0	3.2	6.2	9.4	1567	16.6	√	√	√
S-20-0	2.7	5.4	8.1	1534	15.7	√	√	√
S-25-0	2.5	4.9	7.4	1486	14.8	√	√	√
E-0-10	2.8	5.6	9.3	1720	17.7	√	X	√
E-0-15	2.8	5.4	7.5	1550	18.4	√	√	√
E-0-20	2.2	4.8	5.8	1477	21.2	X	√	X
E-0-25	1.8	3.2	4.8	1447	24.5	X	√	X
SE-10-20	4.1	8.0	11.7	1574	17.2	√	√	√
SE-12.5-20	3.6	6.2	9.3	1571	16.2	√	√	√
SE-15-20	3.1	5.4	8.3	1566	15.6	√	√	√
SE-10-22.5	4.1	6.8	10.4	1563	17.7	√	√	√
SE-12.5-22.5	3.4	5.4	9.2	1531	16.6	√	√	√
SE-15-22.5	3.2	5.2	7.4	1529	16.6	√	√	√
SE-10-25	3.4	5.8	8.5	1538	18.0	√	√	√
SE-12.5-25	2.9	5.1	7.1	1520	17.6	√	√	√
SE-15-25	2.4	4.8	7	1512	17	√	√	√

Notes: $f_{c,i}$, ρ_i and WA_i are the compressive strength, density and water absorption of the mix, while $f_{c,ctl}$, ρ_{ctl} and WA_{ctl} represent the properties of the normal-cement brick (mix C-0-0).

From Table 6, the following is observed:

a. All the bricks met the strength requirement of at least 3.5 N/mm^2 stated by IS 1077. Most of them (88.9%) fulfilled 7 N/mm^2 requirement by BS 3921. The mixes failed to reach 7 N/mm^2 compressive strength when EFB fibre content exceeded 20%,
b. Majority of the bricks (88.9%) were considered lightweight. The densities were less than 1680 kg/m^3.
c. None of the bricks, including the normal cement brick, met the requirement of less than 7% water absorption defined by BS 3921. 88.9% of them complied with IS 1077 with less than 20% water absorption. The bricks that did not comply with the requirement had EFB fibre content of more than 20%

3.2 Compressive Strength

The bricks presented a typical growth of the compressive strength as a cementitious mix. The strength increased by age, achieving about 1/3 and 2/3 of the matured strength, f_c, on days 3 and 7, respectively.

3.2.1 Effects of SF

The brick with 10% SF content (mix S-10-0) offered the highest compressive strength (Figure 2(a)). Its strength was 10% higher than the normal cement brick (mix C-0-0) (Table 7). The pozzolanic reaction triggered by SF during the hydration process improved the interfacial bond between the cement paste and the sand (ACI Committee 234:2006, 2006; Rossignolo, 2007; Rasol, 2015).

However, excessive SF content can affect the strength of the bricks. Cement bricks with 25% SF content (mix S-25-0) offered 35% lower strength than the normal cement brick (mix S-10-0) (Table 7). This could be due to the high water demand of SF for its fine particle. It reduced the free water in the mix, which led to segregation and clogging. This affected (a) the efficiency of the chemical and pozzolanic reactions in the mix, and (b) the workability and the quality of compaction of the fresh cement mix. Thus, the strength of the brick was affected.

For the scarcity of the free water in the mix, some portions of SF might not undergo the pozzolanic reaction and maintained in its original form. This led to a risk of leaching of SF, especially when in contact with moisture. For that, an excessive amount of SF is not recommended. This is in line with the principle by ACI Committee 234 to avoid the use of SF unless the data shows a favourable performance in concrete.

Table 7. Chemical composition of cement and micro-silica (%)

Mix	Strength ratio $f_{c,I} / f_{c,ctl}$	Density ratio ρ_i / ρ_{ctl}	Water Absorption ratio WA_i / WA_{ctl}
C-0-0	1.00	1.00	1.00
S-10-0	1.10	1.07	0.97
S-15-0	0.83	0.95	0.92
S-20-0	0.72	0.93	0.87
S-25-0	0.65	0.9	0.82
E-0-10	0.82	1.04	0.98
E-0-15	0.66	0.94	1.02
E-0-20	0.51	0.89	1.17
E-0-25	0.42	0.87	1.35
SE-10-20	1.04	0.95	0.95
SE-12.5-20	0.82	0.95	0.90
SE-15-20	0.73	0.95	0.86
SE-10-22.5	0.92	0.94	0.98
SE-12.5-22.5	0.81	0.93	0.92
SE-15-22.5	0.65	0.92	0.92
SE-10-25	0.75	0.93	0.99
SE-12.5-25	0.63	0.92	0.97
SE-15-25	0.62	0.91	0.94

Notes: $f_{c,i}$, ρ_i and WA_i are the compressive strength, density and water absorption of the mix, respectively, while $f_{c,ctl}$, ρ_{ctl} and WA_{ctl} represent the properties of the normal-cement brick (mix C-0-0).

3.2.2 Effects of EFB Fibre

EFB fibre content affected the compressive strength of the cement brick (Figure 2(b)). The strength reduced 18% when 10% of sand was substituted by EFB fibre (mix E-0-10) (Table 7). It further reduced to 58% when 25% of EFB fibre was used (mix E-0-25). This was mainly attributed to the physical and mechanical properties of EFB fibre; (a) porous and low density, (b) low tensile strength, (c) poor adhesive bond between EFB fibre and cement paste.

According to Ismail and Yaacob (2011) and Kadir *et al*. (2017), organic fibres, when used in a small amount (3% to 5%), slightly increased the strength of brick. The fibre that evenly stated in various directions (a) reinforced the mix (Binici, Aksogan and Shah, 2005), (b) absorbed and distributed stresses within the mix and delayed the propagation of micro-cracks in the bricks (Raut and Gomez, 2017).

However, this principle was not applicable in this study, particularly when a large portion of sand was replaced by EFB fibre. For the inferior physical and mechanical properties of EFB fibre, an excessive replacement of sand with EFB fibre shall unsurprisingly weaken the brick. To overcome this problem, the mechanical properties of EFB fibre should be enhanced.

EFB fibre was found affecting the workability of the fresh cement mix. Calatan *et al*. (2016) observed a similar response as the hemp fibre content increased. This was owing to (a) the compressible characteristic of EFB fibre, which hindered it from flexibly deforming in the mix during compaction, and (b) the hydrophilic characteristic of EFB fibre, which reduced the amount of free water in the fresh cement mix. Consequently, the uniformity and degree of compactness of the mix were affected, and thus, brick became weaker in strength.

Taking 7 N/mm^2 compressive strength limit as the reference, the replacement of sand by EFB fibre should not exceed 15% (Figure 2(b)).

3.2.3 Combined effects of SF and EFB Fibre

In SF-EFB-cement bricks, SF increased the strength, while EFB fibre reduced it. This was evident when SF-EFB-cement brick was always stronger than EFB-cement brick but weaker than SF-cement brick (Figure 2(c) and (d)).

SF managed to regain the strength loss caused by EFB fibre in the mix. Cement brick with 10% SF and 20% EFB (mix SE-10-20) offered a comparable compressive strength (4% higher) as the normal cement brick (mix C-0-0).

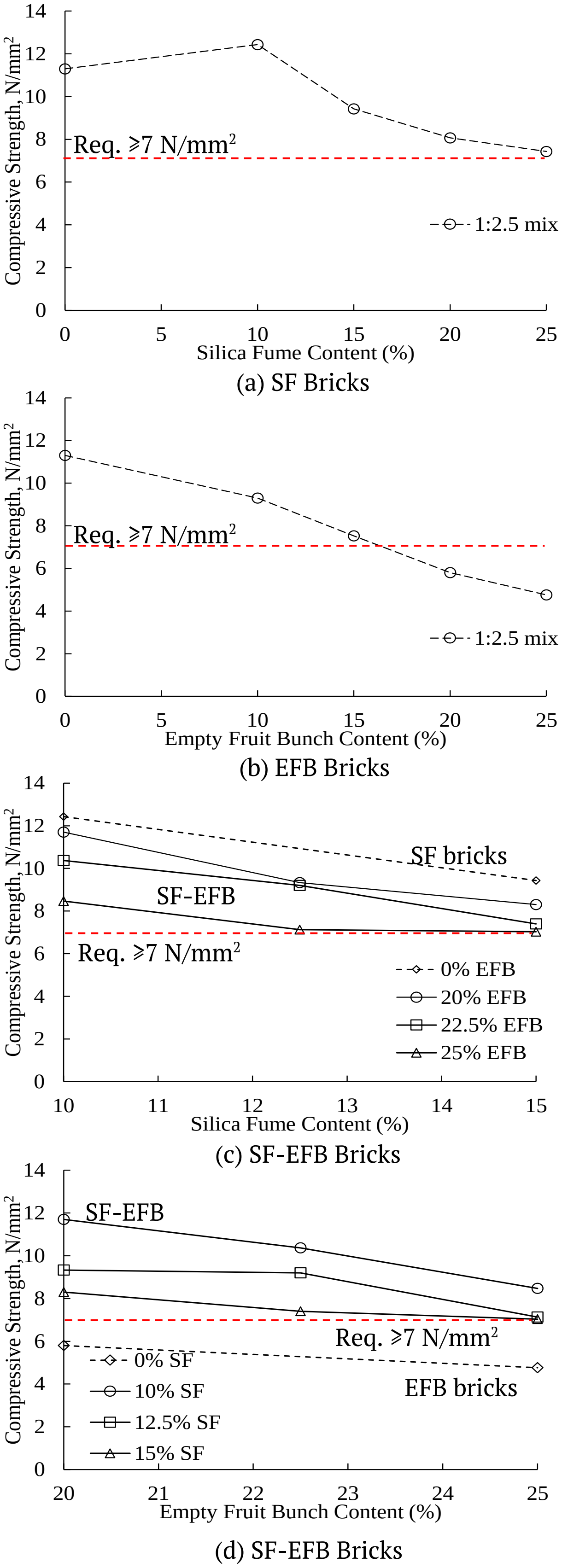


Figure 2. Effects of SF and EFB on the compressive strength of Cement Bricks

3.3 Density

88.9% of the bricks had a density of less than 1640 kg/m^3 (Table 6). Thus, the bricks are considered lightweight. Such characteristic is preferred for (a) easy handling during the construction, and (b) reduced weight imposed onto the structure.

3.3.1 Effect of SF

The density decreased as SF content increased (Figure 3(a)). It reduced by 10% when 25% of SF was mixed. A similar response was observed by Samander, Dwivedi, and Agarwal, 2013.

SF should theoretically not influencing the density of the concrete mix, provided the fresh cement mix is properly mixed and compacted (ACI Committee 234:2006, 2006). The reduced density in this study could be due to the difficulty of compaction caused by low workability of the fresh cement mix, in consequence of the high water demand of SF that reduced the amount of free water in the mix.

3.3.2 Effect of EFB Fibre

The density decreased as EFB fibre content increased (Figure 3(b)). A similar response was observed from the previous studies (Kolop, Haziman and Eng, 2008; Ismail and Yaacob, 2011; Danso *et al.*, 2015; A. A. Kadir *et al.*, 2017; Raut and Gomez, 2017). This was due to the micro-pores and voids in the cellular structure of EFB fibre that replaced the sand in the mix (Raut and Gomez, 2017). For the compressible characteristics of EFB fibre, the degree of compactness of the brick was affected.

3.3.3 Combined effects of SF and EFB Fibre

The increase of SF and FEB fibre contents reduced the density of the SF-EFB-cement bricks (Figures 3(c) and (d)). This is expectable based on their individual effects on the density (Figures 3(a) and (b)).

The density of EFB-cement brick was found lower than SF-EFB-cement brick (Figure 3(d)). SF seemed to slightly increase the density of EFB bricks. This could be due to the filling of the micro-pores of EFB fibres by SF during the mixing process.

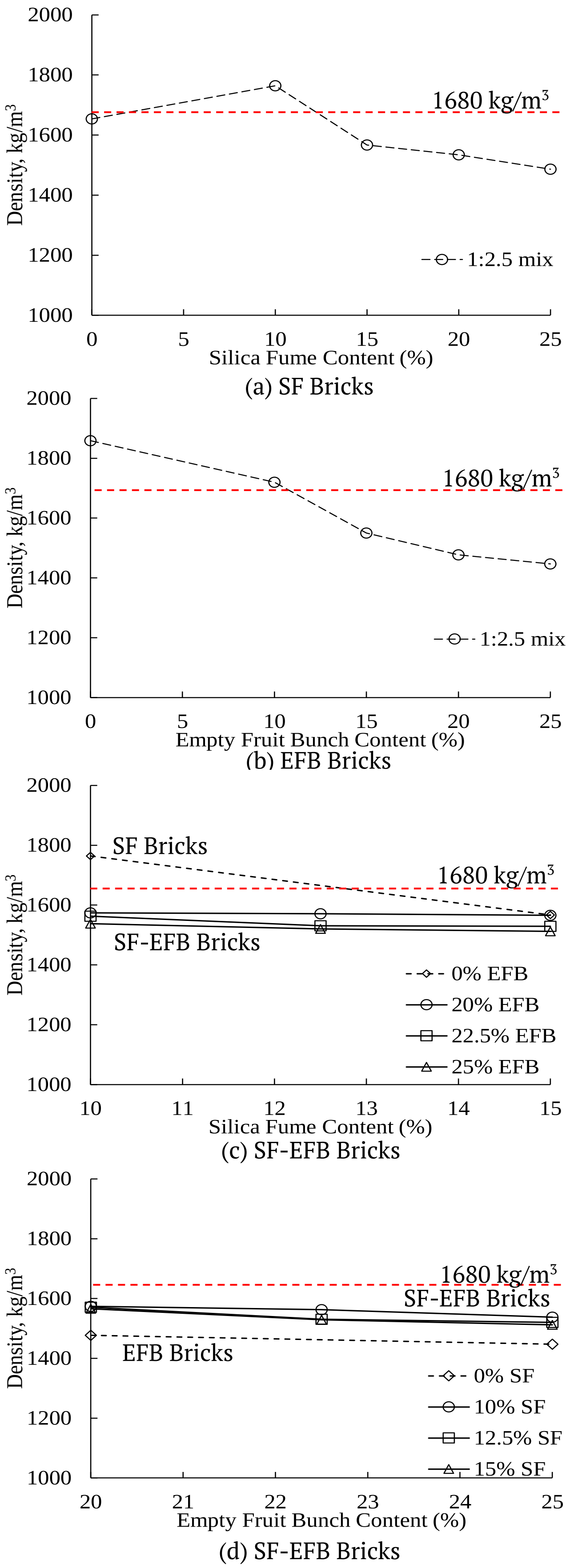


Figure 3. Effects of SF and EFB on the density of Sand-Cement Bricks

3.4 Water Absorption

3.4.1 Effects of SF

The water absorption of brick reduced as SF content increased (Figure 4(a)). A similar response was observed from the previous studies (ACI Committee 234:2006, 2006; Al-Oraimi *et al.*, 2007; Hegazy, Fouad and Hassanain, 2012; Thirugnanasambantham *et al.*, 2017). Al-Oraimi *et al.* (2007) associated this to the filling of the SF particles in the microscopic voids in the mix, which subsequently reduced the porosity and permeability of the brick.

However, there were studies reporting an opposite response, where the water absorption increased as SF content increased (Elbeyli *et al.*, 2004; Al-Khafaji and Hussein, 2013; Samander, Kumar Dwivedi and Agarwal, 2013). No explanation was given by the respective papers.

SF is believed to reduce the rate of water absorption, but impose no effect on the degree of saturation of the cement brick (ACI Committee 234:2006, 2006). This might explain the inconsistent effects of SF on water absorption, as observed by different researchers under different circumstances.

3.4.2 Effects of EFB Fibres

Water absorption of the bricks increased as EFB fibre content increased (Figure 4(b)). This was attributed to the hydrophilic characteristic of EFB fibre due to the presence of micropores in its cellular structure (Ismail and Yaacob, 2011).

3.4.3 Combined Effects of SF and EFB Fibres

SF reduced the water absorption of EFB-cement brick by 18.8% to 26.5%, as observed from SF-EFB- and EFB-cement bricks in Figure 4(d). It reduced the water absorption to a state comparable to SF-cement bricks (Figure 4(c)). The filling of the micropores of EFB fibres by the fine particles of SF had reduced the porosity and permeability of the brick.

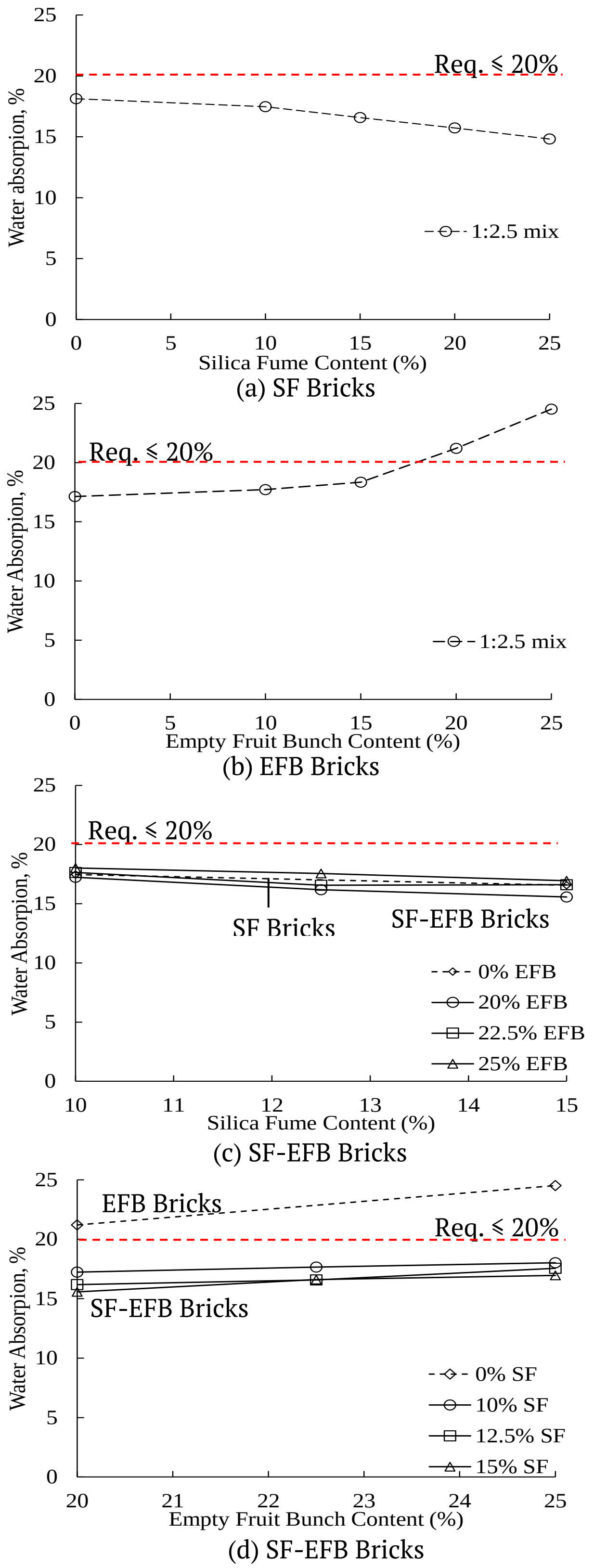
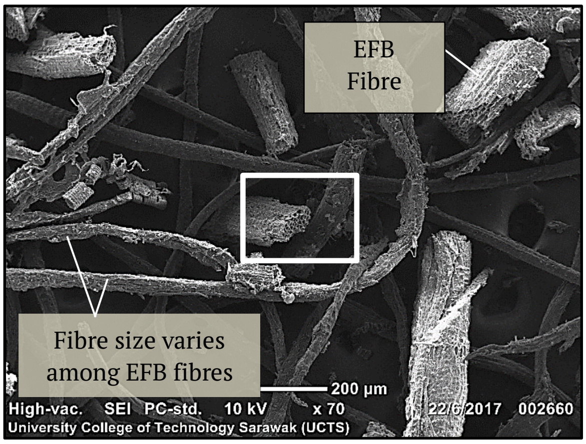


Figure 4. Effects of SF and EFB on the water absorption of Sand-Cement Bricks

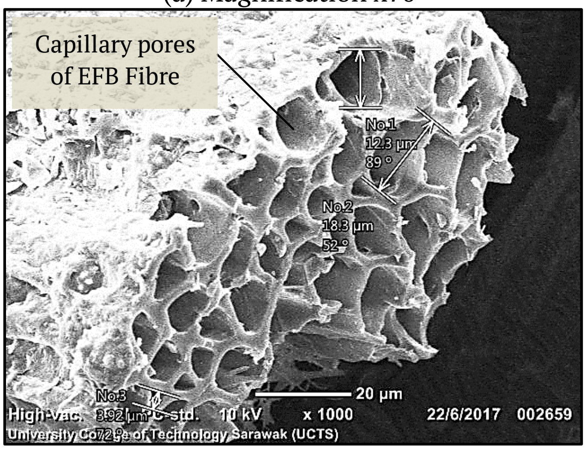
3.5 Microstructure

Figure 5 exhibits the microstructure of EFB fibre. The cellular structure was made of an enormous amount of fine ligneous-like cellulose fibres. The fibres were irregular in size; the diameter ranged from 20 μm to 475 μm, as estimated from Figure 6. It was porous and contained a considerable amount of micropores in the longitudinal and perpendicular directions. The pore size ranged from 3.92 μm to 18.3 μm (Figure 5(b)).

Figure 6 shows the microstructure of EFB fibre filled with SF. Fine SF particles occupied the space in the micropores of the cellular structure. Thus, the density increased and the water absorption decreased when SF was added to the mix of EFB-cement bricks.

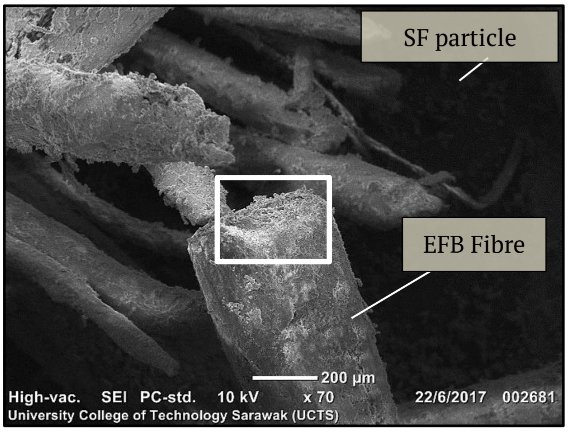


(a) Magnification x70

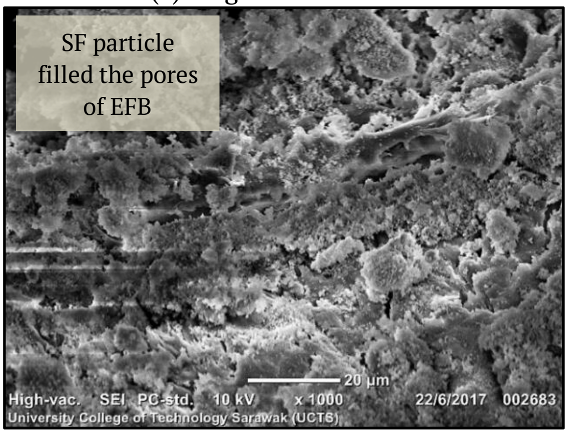


(b) Magnification x1000

Figure 5. Micro-pores of EFB Fibre



(a) Magnification x70



(b) Magnification x1000

Figure 6. Micro-pores of EFB Fibre filled with SF

4 CONCLUSION

This study aimed to determine the feasibility of applying SF and EFB in the brick manufacturing industry. The specimens were distinguished in the categories of the normal, SF-, EFB- and SF-EFB-cement bricks.

It is concluded that:

a. SF may substitute less than 10% of cement in the cement brick to increase the compressive strength.
b. For the micropores of the cellular structure, EFB fibre reduced the strength and density but increased the water absorption of the cement brick, making it less preferred for the application in the construction industry.
c. Such detrimental effects were neutralized by SF through the filling of the micropores of EFB-fibre.

However, the filling of SF in the micropores of EFB fibre is still hypothetical and no relevant literature is found thus far.

Based on the proposed evaluation criteria, in the absence of SF, EFB fibre content should not exceed 15%. In the presence of SF, EFB fibre could substitute 25% of sand in the brick. For a comparable strength as the normal cement brick, the mix proportion would be 10% and 20% SF and EFB fibre contents respectively.

The recommendations were made based on the considerations of the compressive strength, density and water absorption properties only. It should not be applied in the industry, unless the other concerns are resolved, such as:

a. SF must not leach from the SF-EFB-cement brick.
b. The consistency of the physical and mechanical properties of EFB fibre as a natural fibre is confidently ensured.
c. The brick, which constitutes a large amount of EFB fibre, must not be easily combustible.

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REFERENCES

ACI Committee 234:2006 (2006) *Guide for the Use of Silica Fume in Concrete*.

Ajay, V. and Rajeev, C. (2012) 'Effect of Micro Silica on The Strength of Concrete with Ordinary Portland Cement', *Research Journal of Engineering Sciences*, 1, pp. 1–4.

Al-Khafaji, B. T. and Hussein, A. N. (2013) 'Effect of milted clay brick powder on properties of clay brick with additional of silica fume', *Journal of Babylon University*, 21, pp. 528–535.

Al-Oraimi, S. K. *et al.* (2007) 'Compressive Strength and Surface Absorption of High Strength Silica Fume Concrete Under Different Curing Conditions', *The Journal of Engineering Research [TJER]*. SciTech Solutions, 4(1), pp. 17–22. doi: 10.24200/tjer.vol4iss1pp17-22.

ASTM International (2011a) *ASTM C140 – 11a Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units*.

ASTM International (2011b) *ASTM C1634-11 Standard Specification for Concrete Facing Brick*.

Awalludin, M. F. *et al.* (2015) 'An overview of the oil palm industry in Malaysia and its waste utilization through thermochemical conversion, specifically via liquefaction', *Renewable and Sustainable Energy Reviews*, pp. 1469–1484. doi: 10.1016/j.rser.2015.05.085.

Baid, A. S. and Bhole, S. D. (2013) 'Effect of Micro-Silica on Mechanical Properties of Concrete', *International Journal of Engineering Research & Technology*, 2, pp. 230–238.

Binici, H., Aksogan, O. and Shah, T. (2005) 'Investigation of fibre reinforced mud brick as a building material', *Construction and Building Materials*, 19, pp. 313–318. doi: 10.1016/j.conbuildmat.2004.07.013.

BS 3921:1985 (1985) *Specification for clay bricks*. British Standards Institution. Available at: https://www.thenbs.com/PublicationIndex/documents/details?Pub=BSI&DocID=72040.

BS EN 12390-2:2000 (2000) *Testing hardened concrete - Part 2: Making and curing specimens for strength tests*, *British Standards Institute*.

BS EN 206:2013: (2013) *Concrete — Specification , performance , production and conformity*, *British Standard Institute*.

Bureau of Indian Standards (1992) *IS 1077 : 1992 Common Burnt Clay Building Bricks -Specification*.

Calatan, G. *et al.* (2016) 'Determining the Optimum Addition of Vegetable Materials in Adobe Bricks', *Procedia Technology*, 23, pp. 259–265. doi: 10.1016/j.protcy.2016.01.077.

Danso, H. *et al.* (2015) 'Physical, mechanical and durability properties of soil building blocks reinforced with natural fibres', *Construction and Building Materials*, 101, pp. 797–809. doi: 10.1016/j.conbuildmat.2015.10.069.

Davies, J. C. A. (1974) ‘Inhalation hazards in the manufacture of silicon alloys’, *The Central African Journal of Medicine*, 20, pp. 140–143.

Elbeyli, I. Y. *et al.* (2004) ‘Utilization of Borax Waste, Fly Ash and Silica Fume in Manufacturing of Building Brick’, in *The 2nd International Boron Symposium 2004*. Eskişehir, Turkey, pp. 23–25.

Harsono *et al.* (2015) ‘Properties of Fibers Prepared from Oil Palm Empty Fruit Bunch for Use as Corrugating Medium and Fiberboard’, *Japan Tappi Journal*, 69, pp. 1345–1349. doi: 10.2524/jtappij.1508.

Hegazy, B. E.-D. E., Fouad, H. A. and Hassanain, A. M. (2012) ‘Incorporation of water sludge, silica fume, and rice husk ash in brick making’, *Advances in environmental research*, 1, pp. 83–96. doi: 10.12989/aer.2012.1.1.083.

Hoque, M., Rahman, M. and Islam, N. (2014) ‘Study on the Effect of Silica Fume on the Properties of Brick Aggregate Concrete’, *International Journal of Engineering Research & Technology*, 3, pp. 2436–2442.

Hussain, S. T. and Sastry, K. V. S. G. K. (2014) ‘Study of Strength Properties of Concrete by Using Micro Silica and Nano Silica’, *International Journal of Research in Engineering and Technology*, 3, pp. 103–108. doi: 10.15623/ijret.2014.0310016.

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

Jahr, J. (1980) *Possible Health Hazards from Different Types of Amorphous Silicas -Suggested Threshold Limit Values*, *Institute of Occupational Health*. Oslo, Norway: Institute of Occupational Health. doi: 10.1520/stp38676s.

Kadir, A. A. *et al.* (2017) ‘Feasibility study on utilization of palm fibre waste into fired clay brick’, in *AIP Conference Proceedings*. doi: 10.1063/1.4981861.

Kadir, Aeslina Abdul *et al.* (2017) ‘Physical and mechanical properties by utilizing empty fruit bunch into fired clay brick’, in *AIP Conference Proceedings*. doi: 10.1063/1.4981834.

Kolop, R., Haziman, W. I. M. and Eng, J. W. (2008) ‘Properties of cement block containing high content of oil palm empty fruit bunch (EFB) fibres’, in *International Conference on Civil Engineering Practice (ICCE08)*. Kuantan, Pahang.

Mahjoub, R., Bin Mohamad Yatim, J. and Mohd Sam, A. R. (2013) ‘A review of structural performance of oil palm empty fruit bunch fiber in polymer composites’, *Advances in Materials Science and Engineering*, 9, pp. 1–9. doi: 10.1155/2013/415359.

Malaysian Palm Oil Board (2018a) *Monthly Production of Oil Palm Products Summary for the Month of December 2018*. Available at: http://bepi.mpob.gov.my/index.php/en/statistics/production/186-production-2018/851-production-of-oil-palm-products-2018.html (Accessed: 29 June 2019).

Malaysian Palm Oil Board (2018b) *Number and Capacities of Palm Oil Sectors in Operation as at December 2018 (TONNES/YEAR)*. Available at: http://bepi.mpob.gov.my/index.php/en/statistics/sectoral-status/190-sectoral-status-2018/864-number-a-capacities-of-palm-oil-sectors-2018 (Accessed: 29 June 2019).

Merget, R. *et al.* (2002) ‘Health hazards due to the inhalation of amorphous silica’, *Archives of Toxicology*, 75, pp. 625–634. doi: 10.1007/s002040100266.

Nili, M., Ehsani, A. and Shabani, K. (2010) ‘Influence of nano-SiO2 and microsilica on concrete performance’, in *2nd International Conference on Sustainable Construction Materials and Technologies*.

Parhizkar, T., Ramezanianpour, A. A. and Hillemeier, B. (2002) ‘Assessment of The Use of Silica Fume on Durability of Concretein A Corrosive Environment’. Asian Journal of Civil Engineering (Building and Housing), pp. 13–22.

Rahmani, H. and Ramzanianpour, A. A. (2008) ‘Effect of Silica Fume and Natural Pozzolanas on

Sulfuric Acid Resistance of Dense Concretes', *Asian Journal of Civil Engineering*, 9(3), pp. 303–319.

Ramezanianpour, A. A., Rezaei, H. R. and Savoj, H. R. (2015) 'Influence of Silica Fume on Chloride Diffusion and Corrosion Resistance of Concrete-A Review', *Asian Journal Of Civil Engineering*, 16(3), pp. 301–321.

Rasol, M. A. (2015) 'Effect of Silica Fume on Concrete Properties and Advantages for Kurdistan Region, Iraq', *International Journal of Scientific & Engineering Research*.

Raut, A. N. and Gomez, C. P. (2017) 'Development of thermally efficient fibre-based eco-friendly brick reusing locally available waste materials', *Construction and Building Materials*, 133, pp. 275–288. doi: 10.1016/j.conbuildmat.2016.12.055.

Rossignolo, J. A. (2007) 'Effect of silica fume and SBR latex on the paste-aggregate interfacial transition zone', *Materials Research*. doi: 10.1590/S1516-14392007000100018.

Samander, S., Kumar Dwivedi, A. and Agarwal, S. D. (2013) *Effect of Silica Fume on Fly Ash Cement Bricks-An Experimental Study*, *IOSR Journal of Mechanical and Civil Engineering*. Available at: www.iosrjournals.orgwww.iosrjournals.org.

Sharma, U., Khatri, A. and Kanoungo, A. (2014) *Use of Micro-silica as Additive to Concrete-state of Art*, *International Journal of Civil Engineering Research*.

Shitole, A. D. and Mathapati, S. (2014) 'The Use Of Micro-Silica To Improve The Compressive And Flexural Strength Of Concrete', *International Journal of Mechanical and Production Engineering*, 2, pp. 38–40.

Tanaka, R. *et al.* (2004) 'Chlorine-free bleaching of kraft pulp from oil palm empty fruit bunches', *Japan Agricultural Research Quarterly*, 38, pp. 275–279. doi: 10.6090/jarq.38.275.

Thirugnanasambantham, N. *et al.* (2017) *Effect Of Silica Fume On Fly Ash Bricks*, *International Journal of Science and Engineering Research (IJ0SER)*.