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The Advantages and Disadvantages of Palm Oil Empty Fruit Bunch on Bricks and Mortar

Jen Hua Ling *, Yong Tat Lim, Wen Kam Leong, How Teck Sia
Centre for Research of Innovation Sustainable Development, School of Engineering and Technology, University of Technology Sarawak, Sarawak, MALAYSIA
Jalan Universiti 96000 Sibu, Sarawak
*Corresponding author: lingjenhua@uts.edu.my

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ABSTRACT Palm oil has a great commercial value in the global vegetable oil market, due to having several beneficial uniqueness such as significant profits and high yields for farmers, as well as effective and efficient land use. As the second-largest producer of palm oil in the world, Malaysia produces an enormous amount of empty fruit bunch (EFB) as biomass waste, whose proper and improper disposal incurs costs and environmental problems, respectively. This EFB fibre is also used to produce bricks and mortar for building construction, due to being a sustainable solution to environmental problems. Therefore, this study aims to analyze the existing literature related to the application of EFB in the civil engineering field. This focused on the properties of the fibre and its effects on bricks and mortar, to gauge the challenges and prospects of EFB products in the local industry. EFB fibre is a porous voluminous cellulose structure, whose properties vary among each other due to diverse origins, species, and biological growth conditions. This is useful in reducing the weight and thermal conductivity of bricks, as well as slightly increasing their tensile and flexural strengths. However, some disadvantages were observed for the EFB bricks, with the workability and compressive strength being lower. The water absorption of this product was also higher than normal bricks. This confirmed that EFB fibre should be minimally used in bricks and mortar. As a natural fibre, concerns are often observed on inconsistent quality, poor fire resistance, and decay risk, which need to be solved before the use of bricks in the construction industry. This study recommends several patterns of improving the strength, quality, and consistency of EFB bricks, such as the alkaline treatment, which roughens the surface area of the product to enhance the fibre-matrix adhesion.

KEYWORDS Oil palm; Empty fruit bunch; Brick; Mortar; Physical and Mechanical Properties.

1 INTRODUCTION

Oil palm (Elaeis Guineensis) is a tropical plant indigenous to West Africa (Awalludin et al., 2015), which was originally treated ornamentally for its pleasant and unique appearance (Alam et al., 2015; Nambiappan et al., 2018). This is presently one of the leading vegetable oils in the global market, which is expected to continuously and rapidly expand from 2019 to 2024, at a compound annual growth rate (CAGR) of 5.7 (Research and Markets, 2020). The plant was initially introduced to Malaysia in 1917 (Nambiappan et al., 2018), where the industry rapidly developed since the 1960s till date, portraying the country as the second-largest producer constituting 26% of the world's demand (Index Mundi, 2022). This led to the following industrial functions, (a) creation of many employment opportunities, (b) contributing to approximately 4.5% of Malaysia's gross domestic product (GDP), and (c) constituting RM 67.5 billion foreign exchange earnings (*Council of Palm Oil Producing Countries*, 2020; Nambiappan et al., 2018). Furthermore, oil palm is harvested in FFB (fresh fruit bunches), where the fruits are removed for extraction in industrial mills. The remains of this process are the empty fruit bunches (EFB), the lignocellulosic biomass wastes abundantly produced by the industry. This indicates that approximately 1.1 tons of EFB are produced for every ton of CPO (Karina et al., 2008)

In 2020, Malaysia reportedly produced 16.73 tons/ha of FFB (Malaysian Palm Oil Board, 2020), with 89.2% (5.23 million ha) of the total planted area of 5.87 million ha being used for matured oil palm plantations (Malaysian Palm Oil Board, 2020). This led to an annual production of 87.5 million tons of FFB, with EFB constituting 23% weight of the fresh fruit bunches to produce 20.1 million tons in a year (Dalimin, 1995). Subsequently, the production of these enormous wastes leads to several disposal problems, as EFB needs to be properly disposed of to minimize environmental impacts. The disposal cost is nevertheless reluctantly borne by the local industry, with only 30% of Malaysian palm-oil mills recycling EFB due to low environmental awareness (Abas et al., 2011). In this industry, the biomass wastes are used as a biofuel for boilers, although their high moisture contents diminished the combustive recycling value (Chang, 2014).These are found to be approximately 60-65% after the steam sterilization process Sulaiman et al. (2011); Yusoff (2006). EFB is also incinerated to ash as fertilizer or soil conditioner (Yusoff, 2006), where lots of white smoke with high water-vapor and fly-ash contents are produced (Babinszki et al., 2021). This disposal method is however discouraged by the Malaysian Environmental Department.

EFB is often illegally open-burnt at the plantation sites due to poor enforcement, leading to environmental apprehension in the nearby localities (Shahriarinour et al., 2011). It is also used as mulch, or simply abandoned to rot at the plantation sites, with quick pileups observed at a slow decomposition rate (Ahmad et al., 2019; Mulyantara et al., 2015; Salim et al., 2012; Singh et al., 2013). This leads to the attraction of pests and causes fouling (Ismail and Yaacob, 2011). However, EFB-based environmental problems are resolved by utilizing EFB fiber to fabricate bricks, due to the steady development of the construction industry in Malaysia. Based on this condition, several previous studies have been performed on the application of this fiber in bricks, with most emphasizing its effects on density, compressive strength, and water absorption. These were observed as the common criteria to assess the feasibility of EFB bricks (Ling et al., 2021a,b). The reviews were also generally exploratory, to determine an optimum mix proportion for EFB fiber. For industrial applications, the knowledge of these fibrous effects was very necessary for various aspects. Therefore, this study aims to analyze the potential application of EFB in bricks and mortar. In this condition, several experimental articles were consulted to acquire the characteristics of this fiber and its effects on the properties of bricks and mortar. The challenges and prospects of the EFB-based elements were also evaluated in the study.

2 PROPERTIES OF EMPTY FRUIT BUNCH

EFB is a voluminous brown bunch abandoned after the separation of palm-oil fruits from the FFB. This is approximately 3.5 kg, 130 mm, 170-300 mm, and 250-350 mm in weight, thickness, length, and width, respectively (Sung et al., 2010; Chang, 2014). It also has an irregular shape, as well as contained 20-25% stalk and 75-80% spikelet (Ng and Choo, 2012). Moreover, the major chemical components are cellulose (23.7-65%), hemicellulose (14.62-35.3%) and lignin (13.1-31.64%), due to the diverse origins, species, and biological growth conditions of the fibre (Kong et al.,

Table 1. Structural composition of empty fruit bunch (wt%)

Cellulose	Hemicellulose	Lignin	Reference
23.7	21.6	29.2	Omar et al. (2011)
23.7-65.0	20.58-33.52	14.1-30.45	Chang (2014)
34.0-40.4	17.2-22.4	23.1-29.6	Ahmad et al. (2019)
37.26	14.62	31.64	Sudiyani et al. (2013)
38.3	35.3	22.1	Kong et al. (2014)
38.73	19.55	21	Idris et al. (2015)
42.0	30.9	14.2	Sun et al. (1999)
43.7	29.02	13.3	Saba et al. (2016)
47.6	28.1	13.1	Baharuddin et al. (2012)
50.4	21.9	10.0	Umikalsom et al. (1997)

Table 2. Physical properties of EFB fibre

Reference	Ismail and Yaacob (2011)	Danso et al. (2015)	Saba et al. (2016)	Rama Rao and Ramakrishna (2020)	Raut and Gomez (2017)	Mahjoub et al. (2013)
Density (g/cm ^{3})	1.3	0.77	0.7 – 1.55	-	-	0.7-1.55
Specific gravity	-	-	-	1.2-1.4	2.13	-
Diameter (mm)	0.25 – 0.6	0.82 – 0.19	-	0.225 - 0.285	0.0194	-
Tensile strength (MPa)	21	141 – 65	50 - 400	80 - 250	35.33	24.9 - 550
Modulus of elasticity (GPa)	-	1.1 - 0.7	1 – 9	-	-	0.48 - 9
Elongation at break (%)	30	-	8 - 18	-	0.05	4 - 18
Microfibril angle (deg)	-	-	42 - 46	-	-	-
Lumen width (µm)	-	-	6.90	-	-	-
Moisture content (%)	11	7.4	-	-	-	-
Water absorption (%)	-	103 - 54	-	120 - 320	0.79	-

2014). Based on these conditions, some variations are also observed in the physical properties of EFB (Table 2). The density and the specific gravity of this fiber are also relatively low, leading to the need to reduce the weight of the EFB-based brick. In this case, a high water absorption rate encourages the moisture utilization of the brick, with great tensile strength also possessed. These conditions are due to the amount of fiber in the mix, with Tables 1 and 2 showing that inconsistent properties were the biggest challenges for the fibrous product. This subsequently led to inconsistent brick quality, with variations reduced when EFB fiber is minimally utilized.

3 RELATED STUDIES

The related reviews that used EFB fiber to produce bricks and mortar are summarized in Tables 3 and 4. These indicated that the bricks contained various materials, such as clay, cement, lime, laterite, and soil (Abdul Kadir et al., 2017; Kadir et al., 2017; Kolop et al., 2008; Ling et al., 2019; Raut and Gomez, 2017; Ismail and Yaacob, 2011; Danso et al., 2015). Subsequently, all these experimental studies investigated the effects of this fibrous product on the physical and mechanical properties of the bricks and mortar, including the workability, density, compressive strength, water absorption, and the drying hardened-mix shrinkage. The preferred conditions of the mix are shown in Table 5.

EFB was generally mixed as fibers, which were normally prepared based on the following before mixing,

(a) Washed with clean water to remove the soil, dirt, and impurities on the surface (Raut and Gomez, 2017; Ling et al., 2019),
(b) Cut into specific lengths, such as 10-15 mm (Kolop et al., 2008), 25 mm (Ismail and Yaacob, 2011), and 40 mm (Ling et al., 2019),
(c) Oven-dried at 100-115oC for 24 hours, to remove the moisture content (Abdul Kadir et al., 2017; Kadir et al., 2017; Ling et al., 2019).

To prevent the mixture's suction, Danso et al. (2015) initially soaked the fibers in water for 48 hours before blending them with the other brick constituents. Raut and Gomez (2017) also performed the alkaline treatment for EFB fiber, to enhance the brick fiber-matrix adhesion. This reflected the immersion of fibers in a 2% dilute Sodium Hydroxide (NaOH) solution for an hour, which was then sun-dried before being placed in the mix. However, EFB was differently utilized in the mixture by some previous reviews, with Kolop et al. (2008) and Rama Rao and Ramakrishna (2020) adding the fiber to the prescribed composition of the control specimen, without discounting the constituents. Kadir et al. (2017) and Ling et al. (2019) also used this fibrous product to replace a specific percentage of soil and sand within the mixture, respectively. In addition, the amount of EFB fiber in the mix was generally quantified by the mass or weight related to the binder (Ismail and Yaacob, 2011; Kolop et al., 2008; Rama Rao and Ramakrishna, 2020; Raut and Gomez, 2016).

Table 3. Experimental studies of bricks containing EFB fibre

Reference	Description	Findings
Kolop et al., 2008	• Investigated the properties (density, drying shrinkage, compressive strength, water absorption and stress-strain relationship) of cement blocks (cement-to-sand ratio 1:6, water-to-cement ratio = 0.55, 100x200x400 mm) containing EFB fiber (10-15 mm length, as well as 0, 10, 20, and 30% by cement weight).	• EFB fiber increased the water absorption and drying shrinkage, as well as decreased the density and the compressive strength of the cement block. • The brick shrinkage stabilized after 10 days of curing, with usage after 28 days having no problem. • The fiber also altered the elastoplastic characteristics and increased the brick ductility.
Ismail and Yaacob, 2011	• Used EFB fiber (average length = 25 mm, as well as 0, 1, 2, 3, 4, and 5% by cement weight) to reinforce laterite bricks (mix proportion = 70% soil, 24% sand, 6% cement, and size = 216x97x68 mm). • Investigated the effects of EFB fiber on the dimension, density, compressive strength and water absorption of the bricks.	• The density and water absorption capacity was decreased, with the compressive strength of the laterite bricks also increased. • For optimum strength, EFB content should not exceed 3%, to increase 4.2% brick prowess.
Danso et al., 2015	• Investigated the properties of the soil blocks (290x140x100 mm) reinforced by the fibers of sugarcane bagasse, oil-palm fruit, and coconut husk (0.25, 0.5, 0.75, and 1% by weight). • The blocks were tested for density (BS EN 771-1), water absorption (BS EN 772-11), linear shrinkage, compressive strength (BS EN 772-1), splitting tensile strength (BS EN 12390-6), wearing (ASTM D559-03), and erosion (NZS 4298).	• The natural fibers reduced the density, linear shrinkage, wearing, and erosion while increasing the water absorption, as well as the compressive and tensile strength of the blocks. • Coconut and oil-palm fibers reinforced the soil blocks more effectively than bagasse. • Optimum strength and durability were achieved at 0.5 wt% fiber content.

Reference	Description	Findings
Raut and Gomez, 2017	• Used glass powder (20-35% wt), POFA (20-35% wt), alkaline-treated EFB fiber (0.25-1% wt of binder) crusher dust (20-45% wt), and lime (15% wt) to produce bricks. • The bricks (210x100x100 mm) were tested for water absorption, bulk density, porosity (ASTM C20), compression and flexural strength (ASTM C67 & IS 4860), as well as initial suction rate (BS 3921).	• EFB fiber reduced the thermal conductivity, compressive strength and density while increasing the initial rate of absorption. • The brick with 1% wt met the requirements of the standards on load-bearing strength and water absorption.
Kadir et al., 2017	• Analyzed the effects of EFB fiber (1, 5, and 10%) on the physical and mechanical properties of fired clay brick (215x102.5x65 mm). • This included the shrinkage, density, water absorption, porosity, initial suction rate, and compressive strength. • Used palm fiber (1, 5 and 10%) to partially replace the clay soil in the fired clay brick (215x102.5x65 mm). • The bricks were analyzed based on the density, shrinkage, initial suction rate, water absorption, porosity, and compressive strength.	• EFB fiber decreased the density and compressive strength, as well as increased the firing shrinkage and the initial suction rate of the clay brick. • EFB fiber content should not exceed 5%, to prevent significant loss of strength. • The palm fiber reduced the density and compressive strength, although increased the firing shrinkage, initial suction rate, water absorption, and porosity. • EFB content should not exceed 5%, to prevent significant loss of strength.
Ling et al., 2019	• In sand-cement brick (cement-to-sand ratio = 1:2.5), EFB fiber (10-25%) and silica fume (SF) (10-25%) were used to partially replace the sand and cement, respectively. • The bricks were tested regarding their compressive strength, density, and water absorption.	• SF increased the compressive strength of the brick, with its substation suggested not to exceed 10% of cement. • EFB fiber reduced the strength and density, although increased the water absorption of the cement brick. • SF neutralized the detrimental effects of EFB fiber on the performance of brick. • Without SF, EFB content should not exceed 15%. It is nevertheless expected to reach 25% with 10% SF.

Table 4. Experimental studies of mortar containing EFB fiber

Reference	Description	Findings
Aziz et al. (2014)	1. Investigated the properties of lightweight mortar (w/c ratio = 0.485, cement-to-aggregate ratio = 1:2.75) containing EFB fiber (3-5 cm long with dry surface dry, at 0.5, 1, and 1.5% wt of the cement content) and tire crumb (0, 10, 20, 30, and 40% of fine aggregate volume). 2. The mortar was tested for the workability (ASTM C1437), density (ASTM C642, cube 50 mm), as well as the compressive, split tensile, and flexural strength (ASTM C109, cube 50 mm; ASTM C 496, cylinder 100 x 200 mm; ASTM C348, 40 x 40 x 160 mm).	1. EFB fiber decreased the compressive prowess while increasing the water absorption value, ductility, as well as bond, tensile, and flexural strength of the mortar 2. The optimum mix was 0.5% EFB fiber and 10% tire crumb.
Raut and Gomez (2016)	1. Evaluated the thermal and mechanical performance of the mortar (cement-to-crusher dust ratio = 1:2.75, water-to-cement ratio = 0.485) reinforced with oil-palm fiber (0, 0.5, 1, and 1.5% wt of binder), which contained POFA (10% wt of cement).	1. Oil Palm Fibers (OPF) decreased the density, thermal conductivity and compressive strength of mortar, although increased the flexural prowess, drying shrinkage, porosity, and water absorption.
Rama Rao and Ramakrishna (2020)	1. Investigated the effects of EFB (1, 2, and 3% wt of the cement, 10, 15 and 20 mm fiber length, and dry surface condition) on the workability (IS 4031- part 7-1988), as well as compressive, flexural (IS 4031- part 8-1988), and split tensile strength of reinforced cement mortar (mix ratio cement-sand = 1:2, w/c ratio with superplasticizer = 0.45, specimen size = 40 x 40 x 160 mm).	1. EFB fiber reduced the compressive strength, although increased the flexural and split tensile prowess of the mortar. 2. The optimum mix was 2% fiber with an average length of 15 mm.

4 EFFECTS OF EFB FIBRE ON BRICKS AND MORTAR

Table 6 summarizes the effects of EFB fiber in bricks and mortar, as observed by the study experts. This showed that the biomass waste decreased the workability, density, compressive strength, and thermal conductivity of the specimens, although increased the water absorption, as well as flexural, tensile, and split-tensile prowess. The results also proved that the effects on workability, compressive strength, and water absorption were not favorable for building construction.

Based on Table 6, the listed effects were mainly attributed to the characteristics of EFB fibre, including (a) high pole volumes within its cellulose structure, (b) high deformation compressibility and resistance, and (c) low compressive strength (Fig. 1).

According to Raut and Gomez (2017), the cellular structure of EFB fiber was porous through the scanning electron microscopy (SEM) images, subsequently creating mixture voids and reducing the brick density (Ismail and Yaacob, 2011). This structure possessed some stiffness in deformation resistance while enabling the partial recovery of the fiber to its original size after compaction. The compressibility characteristic of EFB also affected the consistency and quality of mixture compaction (Ismail and Yaacob, 2011). Furthermore, the presence of voids reduced the density and thermal conductivity of the brick, indicating the lightweight status (density < 1680 kg/m3) of a block with more than 10% EFB fiber (Kolop et al., 2008). The air trapped within the cellular structure also reduced the overall heat transfer of mortar (Raut and Gomez, 2017), with the voids subsequently accommodating the storage of water. This increased the water absorption capacity of the brick.

Based on the results, dry and porous EFB fibers were found to absorb water, due to the extraction of moisture during the casting process. This re-

Table 5. Characteristics of the mix for brick and mortar

Properties	Explanation
Workability	High workability enables the fresh mix for easier performances, ensures a better consistency of the blend, and leads to reliable brick quality.
Density	A low-density brick is lighter and easier to handle/mobilize, while also imposing lesser dead loads on the building structure (Ling et al., 2020a; Ling et al., 2020b).
Compressive strength	The brick should have adequate compressive strength to sustain loads for handling, stacking, and mobilizing (Ling et al., 2020a; Ling et al., 2020b).
Water absorption	Low water absorption prevents excessive moisture extraction from the mortar and plaster, leading to the effects on the bond strength and aesthetic appeal of the plastered brick surfaces (Ling et al., 2020a; Ling et al., 2020b).
Drying shrinkage	Low drying shrinkage is associated with greater brick dimension accuracy after fabrication, which is a part of the block quality control (Ling et al., 2020a; Ling et al., 2020b). Subsequently, this condition is found to prevent shrinkage cracks (Ghavami et al., 1999).

Table 6. Effects of EFB fiber on the physical and mechanical properties of brick and mortar

Effects	Explanation
Decrease of workability*	1. EFB fiber absorbed the free water that lubricated the movement of the mixture constituents (Aziz et al., 2014; Rama Rao and Ramakrishna, 2020). 2. It also obstructed the flow of the mixture (Olaoye et al., 2013). 3. The rough and irregular surface of this fiber caused additional coherency of the mixture and friction (Ramli and Alonge, 2016). 4. The compressibility characteristic also affected the quality of compaction (Ling et al., 2019). 5. The workability problem was solved by using the surface-dried EFB fiber and providing the superplasticizer in the mix (Rama Rao and Ramakrishna, 2020).
Decrease of density	1. The pores increased the amount of void in the mix (Raut and Gomez, 2016). 2. The compressibility characteristics affected the quality of fresh mix compaction (Ling et al., 2019).
Decrease of compressive strength*	1. EFB fiber possessed a lower stiffness and strength than the substituted materials (Rama Rao and Ramakrishna, 2020). 2. It was also compressible and unable to resist axial load (Kolop et al., 2008). 3. This fiber led to a higher void volume content in the mix, enabling more sample compressibility and leading to an early failure (Abd. Aziz et al., 2014). 4. The creation of air voids in the cement matrix reduced the bond strength (Raut and Gomez, 2016).
Increase of flexural, tensile, tensile splitting strengths	1. EFB contributed to the tensile resistance of brick (Abd. Aziz et al., 2014; Rama Rao and Ramakrishna, 2020), due to the redistribution of internal forces from the matrix to the reinforced fibers (Ghavami et al., 1999). 2. It also served as an energy-absorbing mechanism (bridging action) and delayed the formation of micro-crack (Raut and Gomez, 2017). 3. The strength was majorly dependent on the orientation of the fibers, leading to varied considerations between the mixes (Rama Rao and Ramakrishna, 2020).
Increase in water absorption*	1. The porous structure provided space for the accommodation of water molecules (Abd. Aziz et al., 2014; Raut and Gomez, 2016).
Decrease of thermal conductivity	1. The formation of air voids by the porous fiber reduced the efficiency of heat transfer (Raut and Gomez, 2016).

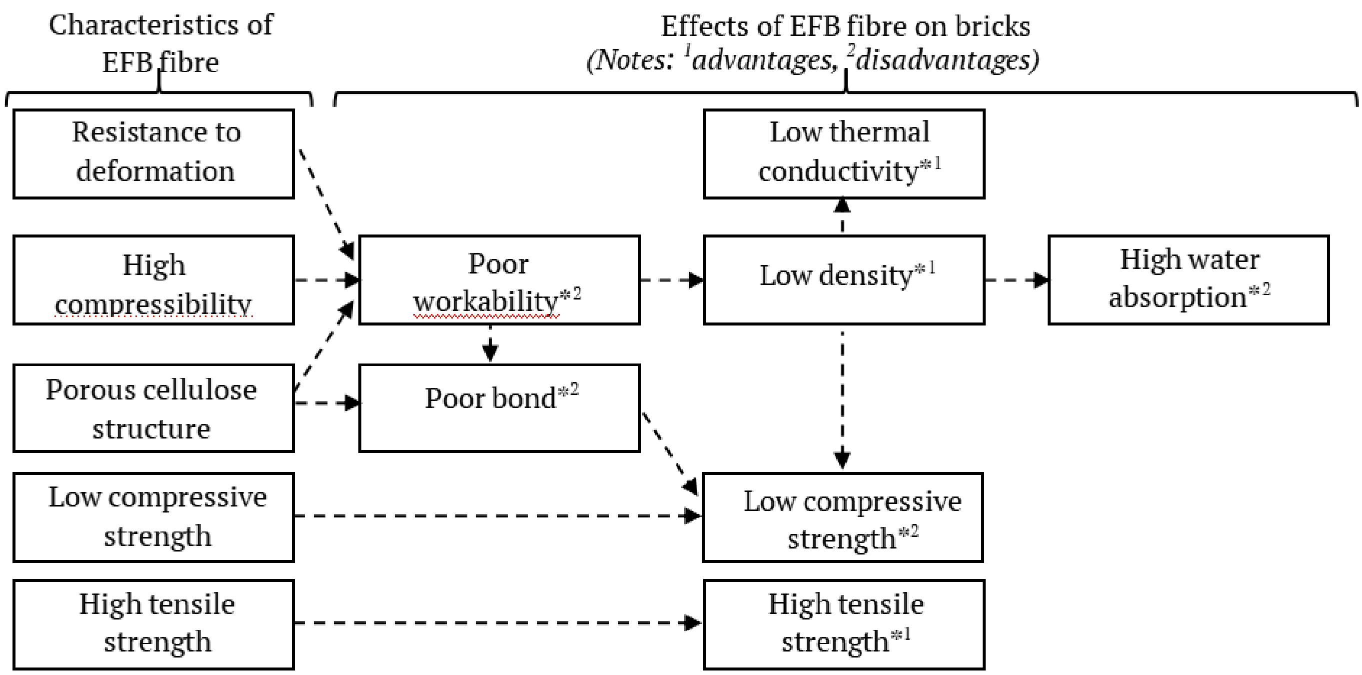

Figure 1 Effects of characteristics of EFB fibre on the properties of bricks.

duced the free water lubricating the constituents' movement and affected the workability of the fresh mix (Aziz et al., 2014; Rama Rao and Ramakrishna, 2020). In a cementitious mix, excessive extraction of the water also influenced the hydration process, leading to subsequent effects on the compressive strength of this brick. To prevent excessive water absorption, EFB fibre was used in saturated and surface-dried forms (Danso et al., 2015), with the workability improved by providing a superplasticizer in the mix (Rama Rao and Ramakrishna, 2020). Additionally, the other reasons responsible for a low compressive strength included,

(a) Low EFB compressive strength (Rama Rao and Ramakrishna, 2020; Kolop et al., 2008),
(b) Poor compaction quality during casting (Ling et al., 2019),
(c) The poor bond between the fibre and cement/soil matrix (Raut and Gomez, 2016), and
(d) Large void volume in the EFB brick (Aziz et al., 2014).

The results confirmed that EFB fiber slightly increased the tensile and flexural strengths of the brick (Aziz et al., 2014; Rama Rao and Ramakrishna, 2020), indicating the occurrence and distribution of stress (Ghavami et al., 1999). This delayed the micro-crack formation developed in the brick (Raut and Gomez, 2017). However, the tensile strength of the brick slightly varied due to the random orientation and inconsistent cross-sectional size of EFB fibers in the mix (Rama Rao and Ramakrishna, 2020; Mahjoub et al., 2013). Based on these results, the mixed proportion of EFB fibre in bricks and mortar was differently recommended by various experts, such as 0.5, 1, 2, 3, and 5% wt of the binder (Aziz et al., 2014; Danso et al., 2015; Raut and Gomez, 2017; Rama Rao and Ramakrishna, 2020; Ismail and Yaacob, 2011; Abdul Kadir et al., 2017; Kadir et al., 2017). This confirmed that EFB content barely exceeded 5% to prevent a significant reduction of compressive strength.

5 CHALLENGES AND PROSPECTS

Due to being a renewable resource abundantly produced by the palm oil industry, the successful application of EFB fiber in bricks and mortar leads to the following benefits,

(a) The reduction of reliance on non-renewable resources, such as sand, clay, laterite, and cement.
(b) Decrease in the cost of the building materials.
(c) The reduction of biomass waste directly disposed to the environment.

Table 7. Advantages and disadvantages of typical natural fiber (Sanjay et al., 2019)

Advantages	Disadvantages
1. Low specific weight leads to high strength and stiffness 2. Cheap renewable resources 3. Good thermal and acoustic insulating properties 4. Biodegradable	1. Lower strength 2. Variable quality 3. Poor moisture resistant 4. Lower durability 5. Poor fire resistant 6. Poor fiber-matrix adhesion

Despite these results, the consumption rate of EFB was still very lower than the production of the palm oil industry. This proved that only a small amount of the fiber (⩽5% wt of the binder) was utilized in bricks and mortar, to prevent the irregular functionality of the building materials. Moreover, EFB mortar was highly mixed in the construction sites than the factory fabrications fabricated in the factories, although had issues with the mixture quality and consistency. This verified that EFB application in the mortar was practical under the present industrial procedures. Some disadvantages of EFB-based bricks that need to be addressed were also observed, due to being closely related to the waste's characteristics as a natural fiber (Table 7).

The physical and mechanical properties of EFB fibers were also found to be very inconsistent (Virk et al., 2010), due to being conditional on various aspects such as size, growth phase, geographical location, soil condition, and climate effects (Chang, 2014). This was because the variations existed within the same plant, regarding the irregular cross-sectional area of the fiber (Mahjoub et al., 2013), subsequently leading to the inconsistent engineering properties of the EFB-based brick. These results were a concern to the mass production of bricks, using EFB fiber from several plantation sites. To overcome these challenges, a standardized procedure needs to be carried out while removing OPF from FFB or treating EFB fibers. This was to ensure the utilization of a consistent fiber quality for the fabrication of bricks, through the following (a) regulating the moisture content of EFB fiber, (b) internally and externally removing the impurities of the fiber pore structure, and (c) strengthening the cellular structure of EFB fiber. Furthermore, several EFB modification attempts were conducted through alkaline treatment or mercerization (Raut and Gomez, 2016, 2017), where lignin, hemicellulose, and other natural fiber contents were removed, to roughen the fibrous surface and enhance the fiber-matrix adhesion in bricks (Vishnu Vardhini et al., 2016; Raut and Gomez, 2017).

The results further indicate that an automated grading and classification system was also designed to sort EFB fibers based on specific criteria, where the fibrous product with consistent properties is often selected for the mix. These criteria include the diameter, unit weight and porosity of EFB fiber. Statistical measures were also used to determine the characteristics strength of EFB brick, through extensive experimental testing and data analysis. This was to reliably ensure the design of EFB-based bricks and predict the properties of the fibrous product based on some visible characteristics. Moreover, low compressive strength was one of the major disadvantages of EFB-based brick, which needs to be resolved by the following, (a) enhancing the interfacial bond between EFB fiber and the matrix, (b) strengthening the cellulose structure of the fiber to withstand stresses, and (c) tangling the fibers of various ratios to reinforce the mixture constituents. More suitable methods should also be explored in subsequent studies, towards the realization of sufficient results. To reduce the water absorption capacity, the suction or moisture inflow into the brick voids should be disrupted through the following, (a) filling the micro-pores within the cellulose structure of the fibers, or (b) treating the surface of the cellulose structure towards being waterproof. Despite these results, subsequent reports are still needed to analyze the solutions. Combustibility was also a concern to EFB-based brick, as the fiber was susceptible to burning. This indicated that the large void volume controlling air circulation in the brick subsequently encouraged combustion. In this condition, the decay, moisture, and abrasion resistance of EFB bricks were also questionable, as the fibrous pore structure was observed to accommodate the growth and development of microorganisms, algae, and fungi. This decreased and affected the durability and aesthetic appeal of the blocks. The poor bond between EFB fiber and the mixture also affected the abrasion resistance of the bricks. Therefore, the performance of relevant studies is futuristically recommended for the assessment of severe issues and the development of several problem-solving techniques.

6 CONCLUSIONS

The feasibility of using palm oil empty fruit bunches (EFB) to produce bricks and mortar was reviewed in this study, where the fiber practically had a higher utilization potential. This was advantageous in reducing the density, thermal conductivity, workability, and compressive strength of bricks. It also encouraged water absorption, as well as slightly increased the tensile and flexural strength. As a structural element, these effects were found to be unfavorable to the brick, with the sole allowance of minimum EFB fiber application. Despite these results, the development of this brick was still at the exploratory stage, where most studies focused on learning the physical and mechanical properties of EFB-based products. This revealed that the techniques used to produce the EFB bricks were quite straightforward, based on the addition of clean fiber into a mix without much treatment. Furthermore, the experts generally evaluated the feasibility of these blocks based on some critical properties, such as strength, density and water absorption, which were still not thoroughly analyzed. For these bricks, some weaknesses were observed based on inconsistent quality, low compressive strength, high water absorption, easily combustible, as well as decay and abrasion susceptibility. These limitations need to be addressed before the real application, with the results obtained providing some possible directions for future reports. To overcome the problems related to EFB brick, the proposed solutions were hypothetical and still at the conceptual stage, indicating the necessity to futuristically conduct a viability test in subsequent reviews.

DISCLAIMER

The authors declare no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the author.

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