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Research Article

Utilization of Oil Palm Empty Fruit Bunch (EFB) Waste as a Mixing Material for Interlocking Brick Production

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Abstract

The choice of building materials has a considerable influence on the reliability of a building. Conventional bricks, despite their frequent use, pose a challenge due to their weight, as they affect the load-bearing capacity of the building, unlike interlocking bricks, which have holes at the top and bottom for reinforcement, potentially reducing the effects of earthquakes. In this study, interlocking bricks made from a mixture of empty oil palm fruit stalks and sand with different sand replacements (0%, 2.5%, 5%, 7.5%, 10%, and 12.5%) are investigated. The research results consistently show that the average density of EFB fiber composite bricks with a density of 1.48 grams/cm³ is lower than that of standard composite bricks. Although the compressive strength of these bricks is initially lower than that of standard bricks, it increases with the substitution of part of the sand with EFB fibers, although not significantly, with the highest compressive strength observed at a substitution rate of 12.5%, reaching 5.201 MPa. Water absorption rates ranged from 13.97% to 21.99%, which increases compared to standard bricks but still meets the requirements. With ongoing research and innovation, EFB-based interlocking bricks have the potential to address environmental challenges and support sustainable and environmentally friendly building practices.

1. Introduction

Although conventional cement bricks generally have numerous advantages and are used in various applications, they also have disadvantages, such as low tensile strength and higher shrinkage [1]. To overcome these limitations, researchers are looking for solutions such as using steel fibers [2], basalt fibers [3], and others. However, the limited availability and high cost are prompting researchers to explore alternative approaches, such as using abundant and easily accessible natural fibers whose strength is comparable to that of conventional fiber-reinforced cement blocks [4]. Empty Fruit Bunch (EFB), the waste from oil palms, is an abundant by-product. Usually, EFB is air-dried until the moisture content reaches about 40% and then used as fuel in palm oil processing plants. The burnt waste is then used as fertilizer in the plantations or can also be used as mulch, a fertilizer that does not need to be burnt, thus reducing combustion costs. It is claimed that using EFB as mulch benefits plant nutrition's sustainability. Some plantation owners emphasize the significant benefits of EFB as a fertilizer and soil conditioner that effectively recycles plant nutrients and improves soil structure, air circulation, water retention capacity, and soil pH. However, some mill owners choose to accumulate EFB waste due to the additional costs associated with fertilizer production, and direct incineration is not feasible as authorities prohibit open burning to prevent air pollution without recovering usable energy [5].

This concern for the environment has led researchers and practitioners in the construction industry to explore innovative ways to reuse EFB waste. One such way is using EFB waste as a mixing material in manufacturing bricks [6]. However, for normal cement bricks, the EFB fibers can only replace up to 15% and 10% of the sand in the mixes with a cement-to-sand ratio of 1:2.5 and 1:3, respectively, according to the feasibility study [7]. Research is still limited to other types of bricks, such as interlocking bricks. Interlocking tiles are used in this study due to their numerous advantages. Interlocking tiles, with their unique design that allows seamless assembly without mortar, have gained prominence in the construction sector due to their durability, ease of installation, and environmental friendliness [4]. Integrating EFB waste into interlocking tile production solves the waste disposal problem and promises to create a sustainable building material.

Several previous studies have been conducted on using EFB in bricks and other building products, which serve as a reference for this research. Researchers recognize the urgency of finding environmentally friendly solutions, leading to research to transform EFB into valuable building materials [1]. Studies have investigated various techniques for incorporating EFB waste into concrete production [8]. EFB fibers are processed to improve their compatibility with cementitious materials. A literature review by Rao and Ramakrishna [9] described the surface morphology of EFB fibers, physical properties, mechanical properties, and various treatment methods to improve durability. Adding EFB fibers in foamed cement composites reduces drying shrinkage and improves compressive strength. In the study conducted by Ismail and Yaacob [10], the addition of EFB fibers improved the compressive strength of bricks, with the maximum strength observed at a fiber content of 3. Ling et al. [7] used EFB fibers as a partial substitute for sand and silica fume (SF) as a partial substitute for cement in the production of cement bricks. The results show that using 10% SF as a cement replacement increases the strength of cement bricks by 10%. However, adding EFB fibers reduces the strength and density while improving the water absorption capacity. In construction applications, the content of SF and EFB fibers should be limited to 10% and 20%, respectively.

However, research specifically on the use of EFB in the production of interlocking tiles is limited [10]. Considering the unique shape of interlocking tiles, they could be a cost-effective and sustainable alternative to conventional building materials [11]. The use of EFB in the production of interlocking tiles is in line with sustainable building practices. This study investigates additional materials and innovative treatments to improve EFB-based interlocking tiles' properties further and ensure their long-term durability and structural stability. With ongoing research and innovation, EFB-based interlocking tiles have the potential not only to solve environmental problems but also contribute to sustainable and environmentally friendly building practices.

2. Materials and Methods

2.1. Material Used

Dynamix type I cement was used as the bonding material for sand and EFB. The EFBs used were obtained from the waste of the WILMAR company in Pontianak City, West Kalimantan. The EFBs were oven-dried at a temperature of 50°C for 4 hours. The EFBs were cleaned of soil and dirt and cut to an average length of 30 mm.

(a) cleaned (b) oven

Figure 1. Preparations of EFB fibers

According to SNI - 03-2847 – 2002 [12], river sand with a specific gravity and a fineness modulus of 2.61 and 3.32, respectively, was used in the mixture as a fine aggregate. The sand was air-dried at room temperature without direct exposure to the weather. Clean household water was used to mix and harden the interlocking blocks.

2.2. Mix Design

The mix for the production of bricks complies with the British Standard (BS-5628-3) [13] and is calculated based on a cement-to-sand ratio of 1:6, as recommended by Ismail [14]. In this mixing method, the water composition was determined according to Table 1, referring to the study by Panjaitan [15], who originally set the water composition at 1500 ml. However, the authors set this study's initial water composition to 1300 ml to obtain additional data. The addition of EFB fibers starts at 0 %, 2.5 %, 5 %, 7.5 %, 10 %, and 12.5 % of the sand weight, with the initial amount of sand adjusted according to the planned mixture. The tolerance limit for the water content corresponding to SNI 15-2094-2000 [16] is 25%.

Table 1. The requirements for interlocking brick materials

Variations EFB (%)	Cement (kg)	Sand (kg)	Water (ml)	EFB (kg)
0	3	18	1300	0
2.5	3	17.6	1450	0.45
5	3	17.1	1600	0.9
7.5	3	16.7	1800	1.35
10	3	16.2	2000	1.8
12.5	3	15.8	2200	2.25

2.3. Preparation of the Interlocking Brick Specimens

2.3.1. Mixing the Ingredients

Mix all ingredients according to the specified mixing ratio. Stir all ingredients until they are evenly mixed. The mixing ratios for all EFB fiber tile samples are listed in Table 1. All EFB brick ingredients were prepared in 6 sample groups of 6 bricks each to determine the compressive strength and water absorption. Thus, the total number of bricks was 36. This study added five groups of brick samples with different fiber contents ranging from 2.5-12.5%, calculated based on sand weight. The remaining group of bricks contained no fibers and served as control samples. These control samples served as a reference point for comparison with other bricks containing fibers to determine the comparison of the physical and mechanical properties of interlocking bricks. The wastage was 45%, taking into account double wastage (from manual mixing to the pressing machine) and soil weight errors during the pressing of the material.

2.3.2. Pressing Interlocking Bricks

Apply mold release oil to the mold to prevent cracking when the specimen is removed. Then, pour the evenly mixed mixture into the mold for the interlocking blocks until it is full. Close the lid of the mold and secure it. Then, press the top of the mold down until it is fully compacted. Then remove the mold cover, lift the interlocking brick slowly so it does not break, and place it on a curing board. Allow the specimen to cure for the first three days and continue until the 28th day to ensure that the specimen is fully ready for testing. Repeat the same steps for all planned mix variants.

(a) demoulded (b) measuring

Figure 2. Preparation Specimens

2.3.3. Sample Curing

The curing process occurs indoors at temperatures between 26 and 30°C and relative humidity between 76 and 81%. Proper care of interlocking tiles includes protecting them from direct sunlight and rain to maintain quality. To maintain the moisture of the interlocking bricks, they are also moistened with water for three days to prevent severe shrinkage caused by the hydration process of the cement during curing. The bricks are then stored at room temperature for 28 days for testing.

2.4. Testing Procedures

The test specimens for interlocking blocks have the dimensions 250 x 125 x 100 mm.

2.4.1. Appearance Testing

Interlocking tiles must have a smooth, crack-free surface and a good visual appearance. This is checked by careful observation by arranging the bricks on a flat surface, as with the actual masonry work.

2.4.2. Dimensional Testing

Dimensional tests are carried out to assess the uniformity of concrete blocks. The concrete blocks must have a nominal thickness of at least 100 mm with a tolerance of +8%. This test is carried out using a ruler or similar measuring tool. The thickness is measured on five samples, and the average value is recorded.

2.4.3. Compressive Strength Testing of Interlocking Bricks

Each hollow concrete block is measured for its dimensions: length, width, height, and weight. The mortar protruding from the top of the hollow block is then removed by carefully breaking it with a hammer. The specimens are placed on a compression testing machine, with the test plates placed evenly on the top and bottom, with no material or debris to interfere with the compression test results. The compression testing machine is operated at a constant load step. The load is continued until the specimen is crushed, and the maximum load occurring during the test is recorded.

2.4.4. Water Absorption Testing of Interlocking Bricks

The purpose of water absorption tests on concrete blocks is to determine the extent of water absorption, which is significantly influenced by the pores or voids present in the blocks. The blocks are immersed in clean water at room temperature for 24 hours. The samples are then removed from the water bath. Excess water is drained for approximately 1 minute, and then the weight of the wet samples is determined. The blocks are dried in an oven at approximately 105°C for 24 hours. The blocks are removed from the oven and allowed to cool to room temperature. The weight of the dry blocks is then measured, and the absorption rate is calculated by comparing the difference in weight between the wet and dry states.

(a) compressive strength (b) water absorption

Figure 3. Testing Specimens

3. Result and Discussions

3.1. Interlocking Brick Dimension

The incorporation of EFB fibers reduces the density, which reduces the weight of the bricks. In general, the weight of soil-cement bricks is around 5000 grams [17]. For samples A-1 to A-3 without EFB fibers (0%), the average weight of the bricks is 4630 grams. When the EFB fibers account for 2.5% of the sand's weight, the bricks' average weight drops to 4370 grams. Using 5% EFB fibers to replace the sand's weight further reduces the bricks' average weight to 3880 grams, while 7.5% EFB results in an average weight of 3520 grams.

Table 2. Dimension of interlocking brick samples

EFB (%)	Samples	Weight (gram)	Dimensions (mm)			Density (gram/cm3)
			Length	Wide	Height	
0	A-1	4600	250	125	100	1.47
	A-2	4800	250	125	100	1.54
	A-3	4500	250	125	100	1.44
2.5	A-4	4500	250	125	100	1.44
	A-5	4300	250	125	100	1.38
	A-6	4300	250	125	100	1.38
5	A-7	3900	250	125	100	1.25
	A-8	3900	250	125	100	1.25
	A-9	3850	250	125	100	1.23
7.5	A-10	3600	250	125	100	1.15
	A-11	3470	250	125	100	1.11
	A-12	3500	250	125	100	1.12
10	A-13	3200	250	125	100	1.02
	A-14	3300	250	125	100	1.06
	A-15	3200	250	125	100	1.02
12.5	A-16	3000	250	125	100	0.96
	A-17	2800	250	125	100	0.89
	A-18	2800	250	125	100	0.89

Similarly, the average weight of the bricks decreases to 3230 grams when 10% EFB is used and to 2870 grams when 12.5% EFB is used. Each 2.5% increase in EFB fiber content reduces the bricks' average weight by about 9 grams compared to the previous weight.

In all cases, it can be seen that the average density of the EFB-fiber interlocking bricks was lower than that of the control interlocking bricks A – 1 to A – 3. Table 2 shows the lower density of the bricks with fibers because the EFB fibers replaced the heavier components, i.e., the river sand. The reduction in mass density due to the addition of EFB fibers reduces the overall weight distribution during transportation and is, therefore, one of the advantages of EFB fiber composite bricks.

3.2. Compressive Strength of the EFB Fiber Interlocking Bricks

The highest compressive strength test result was achieved with the normal brick variant at 0%, with an average value of 5.788 MPa.

Table 3. Compressive strength results of the interlocking brick samples

EFB (%)	Samples	Compressive strength (MPa)	Average of Compressive strength (MPa)
0	A-1	5.53	5.788
	A-2	5.71	
	A-3	6.12	
2.5	A-4	1.78	1.841
	A-5	1.89	
	A-6	1.85	
5	A-7	1.98	2.060
	A-8	2.30	
	A-9	1.89	
7.5	A-10	1.80	2.317
	A-11	2.33	
	A-12	2.81	
10	A-13	4.56	4.631
	A-14	4.66	
	A-15	4.67	
12.5	A-16	5.19	5.201
	A-17	5.28	
	A-18	5.13	

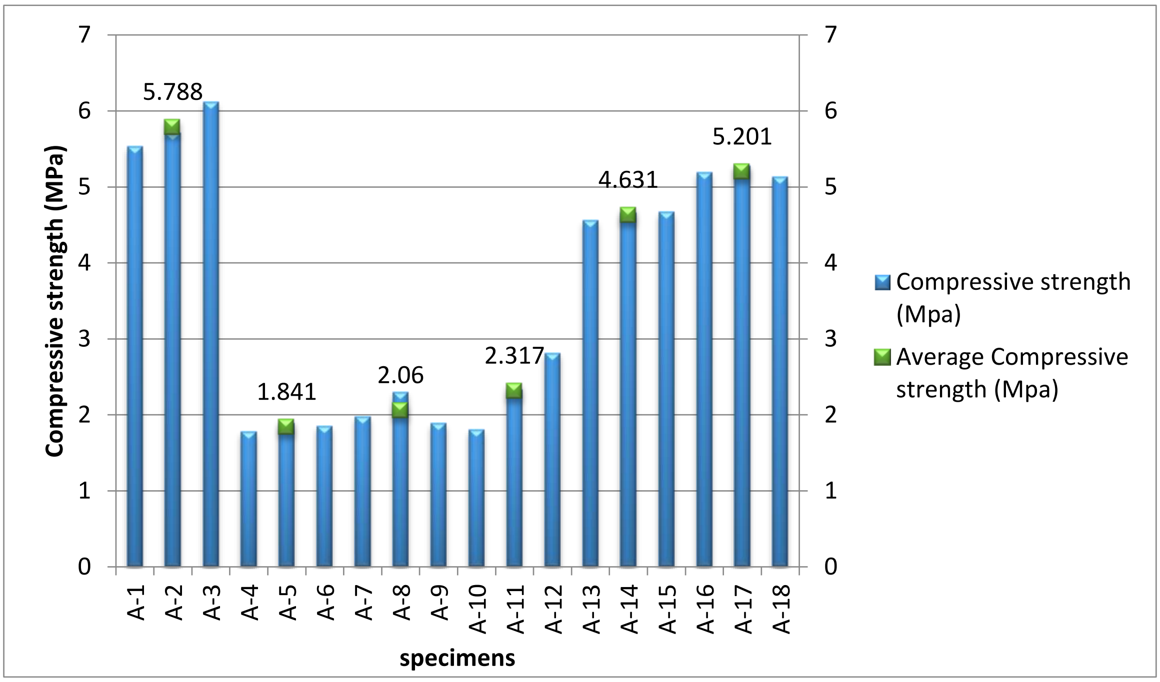

Figure 4. Compressive strength results

According to the physical standards for brick concrete in SNI 03-0349-1989 [18], this value falls into the grade III category with a minimum compressive strength of 4.82 MPa. However, in the samples containing 2.5% EFB fibers, there was a significant decrease in compressive strength by 68.2%, with a value of 1.841 MPa compared to the samples without EFB fibers. This is attributed to EFB fibers in the mix and a low cement-to-sand ratio of 0.167, whereby the limited amount of cement could not adequately bind the sand and EFB fibers.

This result is consistent with the research of Ling et al. [6], which indicated that the cement-sand ratio affects the compressive strength of concrete due to the role of cement as a binder for sand and EFB fibers. Moreover, the compressive strength increases with the gradual increase in the proportion of EFB fibers and the reduction in the proportion of sand. This is because a higher amount of cement can bind the concrete matrix more effectively, especially with the contribution of EFB fibers, considering the decreasing amount of sand to be bound.

The increase in compressive strength can be observed when EFB fibers are used as a substitute for sand in a percentage of 5% to 12.5%, with values ranging from 2,060 to 5,201 MPa. Although according to SNI 03-0349-1989, the use of EFB fibers as a substitute for sand up to 10% does not meet the requirements to be considered as concrete blocks, since the minimum value is not reached, the final result of the compressive strength test when using EFB fibers at 12.5% can exceed the minimum value of 5.201 MPa established by the standard.

This increase is due to increased EFB fibers and reduced sand content. This allows the cement to fill the gaps and pores within the EFB fibers better, which improves the bond between the concrete particles and results in a denser matrix structure. Although normal concrete without EFB fibers has a higher compressive strength, using EFB fibers indirectly increases the compressive strength by supporting the bond within the concrete matrix, albeit not significantly.

3.3. Water Absorption

Based on the water absorption test results for interlocking bricks, it was determined that the minimum water absorption value for normal bricks is 10.91. When EFB fibers from 2.5% to 12.5% were used in the mixture to replace part of the sand, the water absorption test results increased from 13.97% to 21.99% due to the natural properties of EFB fibers as natural fibers with high water absorption capacity. These results indicate that the composition of the blend still meets the specified standards.

Table 4. Water absorption results from interlocking brick

Variations of EFB (%)	Samples	Brick weight after soaking (kg)	Brick weight after oven (kg)	Water absorption of brick (%)	Average of water absorption (%)
0	A-1	1.72	1.53	12.42	10.91
	A-2	1.94	1.76	10.16	
	A-3	1.41	1.28	10.16	
2.5	A-4	1.85	1.60	15.63	13.97
	A-5	1.40	1.25	12.00	
	A-6	1.60	1.40	14.29	
5.0	A-7	1.92	1.68	14.29	15.568
	A-8	1.53	1.31	16.79	
	A-9	1.85	1.60	15.63	
7.5	A-10	1.52	1.30	16.92	18.014
	A-11	1.44	1.21	19.01	
	A-12	1.50	1.27	18.11	
10.0	A-13	2.1	1.77	18.64	20.47
	A-14	1.85	1.51	22.52	
	A-15	1.9	1.58	20.25	
12.5	A-16	2.31	1.9	21.58	21.99
	A-17	2.2	1.8	22.22	
	A-18	2.04	1.67	22.16	

According to SNI-03-0349-1989 [18], the maximum permissible value for water absorption is 25%. Therefore, interlocking blocks with a mixture of EFB fibers between 2.5% and 12.5% are still suitable for further, more comprehensive investigations.

4. Conclusions

The relationship between the densities of interlocking bricks made from EFB fiber and the content of fiber used in their production suggests that higher fiber content leads to lower density due to the displacement of heavier constituents like river sand by the lighter EFB fibers.

While normal bricks initially exhibited the highest compressive strength and met Grade III standards with an average value of 5.788 MPa, the introduction of 2.5% EFB fibers led to a significant decrease in strength by 68.2%, which was attributed to insufficient cement bonding due to a low cement-to-sand ratio, consistent with previous research on the influence of cement-to-sand ratio on the compressive strength of concrete.

However, increasing the proportion of EFB fibers gradually increased the strength and significantly exceeded the minimum standards at 12.5%, attributed to improved fiber presence and lower sand content that improves cement filling. This indicates the potential of EFB fibers as a concrete additive to increase strength, although optimization of the proportion to meet the standards is still pending.

The water absorption tests on interlocking blocks showed that replacing part of the sand with EFB fibers (2.5% to 12.5%) increased the absorption from 13.97% to 21.99% due to the high natural absorption capacity of EFB fibers. However, the mixture still complies with the standards with a maximum absorption limit of 25% (SNI-03-0349-1989). Therefore, interlocking blocks with EFB fiber blends are suitable for further research.

Overall, EFB fibers show potential as reinforcement for interlocking bricks, resulting in lighter bricks with improved compressive strength. However, the incorporation of fibers leads to increased permeability. Therefore, further studies are needed to determine the effects of fiber orientation in the matrix and better understand the bond between cement, sand, and fibers. An investigation of the microstructure is also required. Future research could investigate special EFB treatments to improve the fibers' physical properties and make them less permeable to water.

Declaration of Competing Interest: The author declares no competing interests in this research.

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