Physical and mechanical properties of lightweight concrete with the addition of crude palm oil production wastes

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Abstract. The increased area of oil palm plantations in Indonesia followed by increased production and amount of palm oil waste. One of the waste products of palm oil produced from the process of purifying Crude Palm Oil (CPO) is Spent Bleaching Earth (SBE). This research will utilize SBE waste as sand substitution material in concrete manufacture. The addition of natural fiber from the Empty Fruit Bunches (EFB) in the manufacture of concrete is expected to increase the mechanical strength of concrete that meets the SNI requirements. The process of making concrete begins by mixing all ingredients, stirring, moulding, compacting manual, and curing for 28 days. Concrete making is done by substituting SBE by 10%, 30%, and 50% based on sand weight, and fiber by 2%, 4%, and 6% based on sample volume. The results showed that the substitution of 28.98% SBE for sand weight, and 5.95% EFB based on Light Weight Concrete (LWC) volume, produced concrete with the best properties.

1. Introduction

Indonesia is one of the countries with the largest area of oil palm plantations in the world, as well as the largest palm oil-producing country in the world in the form of Crude Palm Oil (CPO). This has consequences for the amount of waste generated from the CPO oil production process which is getting bigger, such as oil palm Empty Fruit Bunches (EFB) and Spent Bleaching Earth (SBE).

EFB fiber is one of the solid wastes produced in the palm oil industry. The amount of EFB fiber is quite large because it is almost the same as the amount of crude palm oil production. The waste has not been used optimally. The data produced in 2015 for EFB amounted to 30.62 million tons [1]. The biggest components of EFB are cellulose (38-65%), besides other smaller components such as hemicellulose (17-35.3%), lignin (13-37%), and ash (1-6%) [2,3]. The great potential of EFB can be utilized to obtain added value and economic value from this material.

Another type of waste, SBE, is an active ingredient used to adsorb the color pigments contained in CPO to produce clearer oil. SBE is a type of clay with the main composition consisting of SiO₂, Al₂O₃, bound water, and Ca²⁺ ions, magnesium oxide, and iron oxide [4]. SBE bleaching power is due to the presence of Al³⁺ ions on the surface of the absorbing particles so that it can absorb dyes and depends on the ratio of Al₂O₃ and SiO₂ in SBE. Both types of waste, both EFB and SBE fibers can be utilized as a more useful product, one of which is to be made into the concrete or Light Weight Concrete (LWC).
Several studies using EFB fiber as raw material for making concrete or LWC to improve the mechanical properties of concrete, including conducted by [5-8]. Whereas research on the use of SBE in making concrete as a substitute for cement or sand substitutes was carried out by [9-12].

In this research, LWC manufacture by using SBE as sand substituted with 10%, 30%, and 50%, and the addition of EFB fiber is 2%, 4%, and 6% by cement weight. The purpose of this study was to determine the effect of SBE substitution and the addition of EFB fiber on the physical and mechanical properties of concrete. The optimal value of SBE substitution for sand and EFB fiber addition in producing lightweight concrete also measured using response surface methodology. Besides, seen also the durability of concrete to changing conditions as indicated by the treatment cycles wet/dry, to see the changes in the value of compressive strength.

2. Materials and Methods

2.1. Materials

The LWC mixtures were composed of Portland Cement Composites (PCC), sand, water, polycarboxylate based ether superplasticizer from SIKA, SBE, and EFB fibers, as listed in Table 1. Every series of mixtures used to prepare four samples 25 x 5 x 5 cm for bending test, and every four samples 5 x 5 x 5 cm for compressive strength, density, and water absorption test.

| Specimen code | Cement | Sand | SBE | EFB | water | HRWR |
|---------------|--------|------|-----|-----|-------|------|
| Control       | 1      | 3.00 | 0.00| 0.00| 0.6*  | 2 ** |
| S1E0          | 1      | 2.70 | 0.30| 0.00| 0.6*  | 2 ** |
| S2E0          | 1      | 2.10 | 0.90| 0.00| 0.6*  | 2 ** |
| S3E0          | 1      | 1.50 | 1.50| 0.00| 0.6*  | 2 ** |
| S1E1          | 1      | 2.70 | 0.30| 0.02| 0.6*  | 2 ** |
| S2E1          | 1      | 2.10 | 0.90| 0.02| 0.6*  | 2 ** |
| S3E1          | 1      | 1.50 | 1.50| 0.02| 0.6*  | 2 ** |
| S1E2          | 1      | 2.70 | 0.30| 0.04| 0.6*  | 2 ** |
| S2E2          | 1      | 2.10 | 0.90| 0.04| 0.6*  | 2 ** |
| S3E2          | 1      | 1.50 | 1.50| 0.04| 0.6*  | 2 ** |
| S1E3          | 1      | 2.70 | 0.30| 0.06| 0.6*  | 2 ** |
| S2E3          | 1      | 2.10 | 0.90| 0.06| 0.6*  | 2 ** |
| S3E3          | 1      | 1.50 | 1.50| 0.06| 0.6*  | 2 ** |

*) the ratio of water to cement (based on weight)

**) the percentage of superplasticizer to cement (based on weight)

2.2. Methods

2.2.1. EFB pre-treatment

EFB fiber is thought to still contain extractive substances that can reduce compatibility and binding ability with cement, so it requires treatment of EFB fiber. The EFB from the factory is washed thoroughly using water by soaking, beating and draining. Then the fibers are dried by the oven with a temperature of 80°C for 8 hours. After drying, the fiber is mashed up to ± 5cm in size, then scaled down using a refiner disk so that the fiber is between 16 mesh and retained at 40 mesh. To eliminate the extractive substances, the EFB fiber is soaked in clean water for 24 hours, then rinsed with clean water. The treatment is repeated until the extractive substances in the EFB fiber are reduced or lost. Indicators that show a decrease or loss of oil in the fiber, EFB fiber has a pH of 7 or close to 7.
2.2.2. Characterization of SBE, sand, and cement
Density measurements were carried out on SBE, sand, and cement, while the sludge level measurements carried out on the sand. The testing of sludge content also needs to be done, because clay or dirt more than 10% in the sand can inhibit the compacting process and reduce the strength of concrete.

2.2.3. Lightweight concrete manufacture
The first step in the mixing procedure was dry mixing of all the solid components (cement, sand, and SBE) with a mortar mixer. Water was then added to the mixture and further mixed until the mixture was evenly distributed. The superplasticizer was then added and the mixture was again mixed for 3 min. When the mixture was homogenous, the fibers were slowly added and mixing until the mixture was uniform. Molds were filled and the samples were compacted. The samples were removed from the molds after 24 hours and were stored in the water tank for 28 days for the curing process.

2.2.4. Physical testing
The physical parameters investigated in this study were the density and water absorption. The sample size for both tests is 5 x 5 x 5 cm. In the measurement of density, samples that have gone through a period of curing and conditioning are measured by their mass and size. While the measurement of water absorption is done by soaking water samples for 24 hours. Weighing samples before and after soaking. The water absorption test aims to determine the porosity of concrete samples.

2.2.5. Mechanical testing
The mechanical properties investigated in this study were Modulus of Rupture (MOR), Modulus of Elasticity (MOE), and compressive strength. MOR and MOE values were obtained from bending tests, using samples with a size of 25 x 5 x 5 cm, while compressive strength values were obtained from tests using samples with a size of 5 x 5 x 5 cm.

2.2.6. Durability testing with wet/dry cycles treatment
The durability properties investigated in this study was the degradation of compressive strength between LWC with and without wet/dry cycles treatment. Sample with a size of 5 x 5 x 5 cm were treated with wet/dry cycles for 7 times. A wet/dry cycle was defined for this research as 23 hours and 30 min drying in an oven at 60 ± 5°C, air drying at room temperature for 30 min, 23 h and 30 min soaking in water at 20 ± 2°C, and air drying at room temperature for 30 min [13].

2.2.7. Statistical analysis
Multiple averages were compared using an analysis of variance (ANOVA) test with a significance level of 5%. The optimal value of SBE substitution for sand and EFB fiber addition in producing LWC measured using response surface methodology.

3. Results and Discussion

3.1. Materials characteristics
Material characterization was carried out to determine the density of SBE, EFB, sand, and cement. Besides, measurements of sludge from sand are also carried out. The results showed that the density of SBE, EFB, sand, and cement respectively of 0.94 g/cm³, 0.49 g/cm³, 2.06 g/cm³, and 2.75 g/cm³. While the sludge content from the sand obtained a value of 9.6%, which means the sand can be directly used in the manufacture of LWC because the sludge content is smaller than 10%.
3.2. Physical properties of LWC

3.2.1 Density of LWC

The LWC density value is shown in Figure 1. The LWC density value with the addition of SBE and or EFB ranges from 1.63 to 1.91 g/cm³. This density value is lower when compared to the density of the control LWC (without the addition of SBE and EFB), which is 1.93 g/cm³.

Figure 1. The density of lightweight concrete

Based on Figure 1 above, the LWC density value tends to decrease with the addition of SBE. While the addition of EFB tends to increase the density at an additional level of EFB 2% and again decreases at the addition of 4% and 6%. This can occur because the addition of EFB at levels of more than 2% can cause the surface coverage of fibers that can be bound by cement to be reduced so that the bond between the cement and the fiber is not as strong as the LWC with the addition of fiber in low levels. This affects the density of the LWC which decreases when the addition of EFB fiber is more than 2%.

Almost all concrete produced is included in light-weight concrete with a density lower than 1900 kg/m³ (1.90 g/cm³). This shows that the addition of SBE and EFB concrete can be classified as lightweight concrete (LWC) [14]. The surface appearance using SEM from the control LWC and LWC with the addition of SBE and EFB can be seen in Figures 2a and 2b.

Figure 2. SEM micrograph of LWC control (a) with 500x magnification, and LWC with addition of 50% SBE and 6% EFB (b) with 200x magnification
Figure 2a is the result of SEM micrographs in the LWC control sample and Figure 2b is the result of SEM micrographs in the LWC sample with the addition of 50% SBE and 6% EFB. In the SEM micrograph results of the two samples, it can be seen that the calcium silicate hydrate (C-S-H) bond has been formed. The SEM results in Figure 2b show the presence of EFB fibers due to the addition of 6% in the sample.

3.2.2 Water absorption of LWC
The value of water absorption from LWC can be seen in Figure 3. The value of water absorption from LWC with the addition of SBE and or EFB ranges from 0.555-1.316%. This value is greater than the value of LWC control water absorption (0.362%). This happens because EFB as a natural fiber has hygroscopic properties, which means they can absorb water [15].

Based on SNI 03-0691-1996, water absorption in concrete does not exceed 10% [16]. So that good concrete based on water absorption value is concrete that has low water absorption capacity. The water absorption value of all concrete formulations meets SNI.

3.3. Mechanical properties of LWC

3.3.1 Compressive strength
The compressive strength values of the LWC can be seen in Table 2. The average compressive strength values of the LWC with the addition of SBE and EFB (34.62-149.01 kgf/cm²) are lower when compared to the control concrete (151.20 kgf/cm²). The higher addition of SBE tends to result in a lower of LWC compressive strength value. This happens because there is still oil in SBE [17], and the oil can inhibit the hydration process of cement and reduce mechanical properties, including the compressive strength of concrete [18].

However, when viewed from the level of concrete quality based on Indonesian Standard for walls (SNI 03-0349-1989), most of the LWC is classified at the level I quality or the same as control concrete. The decreasing compressive strength value along with the increasing number of SBE is due to the presence of oil content in SBE, which affects reducing the bond strength between cement and SBE, so the compressive strength decreases. Meanwhile, the effect of the addition of EFB does not show a certain pattern. The optimum value of the addition of EFB tends to increase by 6% based on the LWC volume.
3.3.2 Modulus of Rupture (MOR)
The MOR value of the LWC can be seen in Figure 4. The results of the MOR test at the 28 days LWC show that the more SBE additions, the lower the MOR value. The similar reason with the compressive strength, because of the effect of oil, which can inhibit the hydration of concrete and decreasing the mechanical properties of LWC [17,18]. The addition of EFB in the concrete mixture can increase the MOR value, with the optimum value in adding EFB by 4% based on LWC volume.

Addition of EFB 4% can increase MOR in concrete with SBE 10% by 34.11% (from 35.579 kg/cm² to 47.716 kg/cm²). Whereas concrete with the addition of SBE 30% increased MOR by 70.77% (from 33.474 kg/cm² to 57.162 kg/cm²). While concrete with the addition of 50% SBE increased MOR by 7%
Concrete with the addition of 1% recycled fiber can increase concrete MOR by 4% (from 25.194 kg/cm\(^2\) to 26.214 kg/cm\(^2\)).

### 3.3.3 Modulus of Elasticity (MOE)

The MOE value of the LWC can be seen in Figure 5. MOE of LWC at 28 days showed that the more SBE additions, the lower the MOE value. The addition of EFB in the concrete mix can increase the value of MOE, with the addition of 2% EFB to produce the most optimum MOE value. The addition of EFB fibers at various levels can increase the MOE of the LWC with SBE addition. While the optimum MOE occurs in the addition of 2% EFB fibers.

![Figure 5. Modulus of Elasticity of LWC](image)

### 3.3.4. Durability of LWC

The results of durability testing in LWC showed that the addition of SBE resulted in decreased LWC's resistance to weather. This is indicated by the percentage decrease in the compressive strength of the concrete increases with the addition of SBE. The addition of EFB to concrete does not significantly reduce the compressive strength of LWC (Figure 6). The decrease in compressive strength in the wet/dry cycle treatment occurs after 2 cycles, where the debonding occurs in the fiber with cement [13]. In addition to the fiber, embrittlement will occur due to mineralization due to this wet/dry cycle treatment [13]. Good concrete is concrete that has high weather resistance so that it can last a long time when applied to walls, roads, parks, and other outdoor applications.

### 3.3.5. Statistical analysis

Statistical analysis was carried out to determine the effect of different SBE levels and EFB levels on responses in the form of physical properties, mechanical properties, and compressive strength decrease due to the wet/dry cycles process. The results show that there are interactions between SBE factors and EFB factors that affect the response in the form of density, compressive strength, MOR, and MOE. While the response in the form of water absorption is only influenced by the factor of SBE addition, and the durability response is influenced by each factor of SBE addition and EFB addition factor. Based on the analysis of responses surface methodology, the optimum value of the addition of SBE and EFB that can produce LWC with optimum properties is 28.98% SBE and 5.95% of EFB addition.
Figure 6. Percentage decrease of compressive strength after seven times wet/dry cycles

4. Conclusion
The addition of SBE and EFB produces concrete with a density of less than 1.9 g/cm$^3$ and is classified into the LWC. The use of SBE and EFB at various levels has a significant influence on responses. The optimum value of the usage of SBE and EFB that can produce optimum properties of concrete is SBE of 28.98% of the weight of sand, and cement of 5.95% of the volume of concrete.

References
[1] Hambali E and Rivai M 2017 The Potential of palm oil waste biomass in Indonesia in 2020 and 2030 IOP Conf. Ser. Earth Environ. Sci. 65(1) 012050
[2] Khalil HPSA, Jawaid M, Hassan A, Paridah MT, and Zaidon A 2012 Oil Palm Biomass Fibers and Recent Advancement in Oil Palm Biomass Fibers Based Hybrid Biocomposites (Composites and Their Application) (London: In Tech Open) chapter 9
[3] Or KH, Putra A, and Selamat MZ 2017 Oil palm empty fruit bunch fibres as sustainable acoustic absorber Appl. Acoust. 119 9-16
[4] Loh SK, James S, Ngatiman M, Cheong KY, Choo YM, and Lim WS 2013 Enhancement of palm oil refinery waste-Spent Bleaching Earth (SBE) into bio organic fertilizer and their effects on crop biomass growth Ind. Crops Prod. 49 775-81
[5] Ling JH, Lim YT, Leong WK, Jasli E, and Sia HT 2019 Properties of cement brick with partial replacement of sand and cement with oil palm empty fruit bunches and silica fume J. Civ. Eng. Forum 5(3) 289
[6] Lim SK, Tiong HY, and Woon KS 2018 Compressive strength and dimensional stability of palm oil empty fruit bunch fibre reinforced foamed concrete E3S Web Conf. 65 1-10
[7] Omoniyi TE 2019 Potential of oil palm (Elaeis guineensis) empty fruit bunch fibre composites for building applications Agri. Eng. 1(2) 153-63
[8] Musa M, Othuman Mydin MA, and Ghani AN 2019 Thermal properties of foamed concrete with addition of empty fruit bunch (EFB) fiber Int. J. Innov. Technol. Explor. Eng. 8(10) 4662-70.
[9] Tee CK 2010 Performance of spent bleaching earth as cement replacement in concrete [Thesis] University Malaysia Pahang Malaysia
[10] Nalobile P, Wachira JM, Thiong’o JK, and Marangu JM 2019 Pyroprocessing and the optimum mix ratio of rice husks, broken bricks and spent bleaching earth to make pozzolanic cement. Heliyon 5(9) e02443
[11] Wangrakdikul U, Khonkaew P, and Wongchareonsin T 2015 Use of the spent bleaching earth from palm oil industry in non fired wall tiles Int. J. Adv Cult Technol. 3(2) 15-24
[12] Lalitha Devi G, Srinivasa Pasad K, Rani MS, and Bhanu L 2019 Strength and durability research on concrete with partial replacement of cement by rice husk ash and spent bleaching earth Int. J. Recent. Technol. Eng. 8(2 Special Issue 11) 1035-40

[13] Mohr BJ, Nanko H, and Kurtis KE 2005 Durability of kraft pulp fiber-cement composites to wet/dry cycling Cem. Concr. Compos. 27(4) 435-48

[14] [BSN] Badan Standardisasi Nasional 2002 Procedures for planning concrete structures for buildings SNI 03-2847-2002 (Jakarta: Standardization National Agency of Indonesia)

[15] Célino A, Fréour S, Jacquemin F, and Casari P 2014 The hygroscopic behavior of plant fibers: A review Front Chem. 1 1-12

[16] [BSN] Badan Standardisasi Nasional 1996 Paving Block SNI 03-0691-1996 (Jakarta: Standardization National Agency of Indonesia)

[17] Krzyśko-Łupicka T, Cybulska K, Wieczorek A, Możdżer E, and Nowak MJ 2014 The effect of spent bleaching earth ageing process on its physicochemical and microbial composition and its potential use as a source of fatty acids and triterpenes Environ. Sc.i Pollut. Res. 21(18) 10765-74

[18] Almabrok MH, Mclaughlan RG, Vessalas K, and Thomas P 2019 Effect of oil contaminated aggregates on cement hydration Amer. J. Eng. Res. 895 81-9