Applicability of Palm Oil Fuel Ash in Interlocking Compressed Earth Brick – A Preliminary Assessment

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Abstract. This paper presents the preliminary assessment on the applicability of palm oil fuel ash (POFA) as one of the materials used to produce interlocking compressed earth brick (ICEB). Ultrafine size POFA was used to replace the main ingredient for ICEB production which is the clay soil. The percentages of replacement were limited to 0%, 10%, 20%, 30%, 40%, 50%, and 60% by weight of the total clay soil material. The main purpose of conducting the experiment is to identify the most desirable mix through compressive strength test. Result showed that, at the curing age of 28 days, the compressive strength of mixture that substituted with 30%–60% of ultrafine POFA achieved higher strength than the control mixture. Meanwhile, the highest compressive strength was obtained by batch series CP50 (50% clay soil + 50% ultrafine POFA). The experimental studies specified that ultrafine POFA has significant possibilities for application in manufacturing ICEB.

1. Introduction

Manufacturing of bricks has become an essential part of the construction industry, but it contributes heavily to environmental degradation due to the extraction of earth soil, which is the main ingredient for brick production. Hence, a lot of modifications have been done in the mixture composition to manufacture brick [1][2]. Palm oil fuel ash (POFA) is a waste material generated from palm oil mill which is generally disposed to open fields and caused health hazards and environmental pollution problems [3]. POFA has attracted researchers’ interest since the early 90s. It has been popularly evaluated as an alternative raw material for the development of sustainable construction material. Researchers discovered the advantages of POFA as a building material especially when it is used as cement or aggregates replacement in the production of concrete [4][5][6]. It appears to be a beneficial solution in the environmental and economic aspects for the building industry. However, limited studies exist on the incorporation of POFA as part of the material in the production of brick, specifically interlocking compressed earth brick (ICEB) material. This paper presents the preliminary assessment on the mixture design of ICEB incorporating with POFA.
2. Experimental Program

2.1. Materials
All the materials used to produce IC EB such as water, cement, POFA, and earth clay soil are locally available.

2.1.1. Ordinary Portland Cement (OPC). Cap Gajah cement brand manufactured by Cement Industries Sabah was used in this study. The specifications of the cement are in accordance with the method as described in MS 522: Part 1:2007.

2.1.2. Palm Oil Fuel Ash (POFA). POFA was collected from a palm oil mill at Lumadan Sawit Kinabalu, Beaufort, Sabah, Malaysia. Since the POFA collected was in wet condition, it was first dried in the oven at 105 ºC for 24 hr to remove all the moisture content in the POFA. Then, the POFA was sieved to 212 µm to remove coarse particles. The POFA passing 212 µm sieve was grinded using ball mill for 2.5 hr to reduce the coarse size particles to ultrafine size particles of POFA. Malvern Panalytical instrument was used to analyse the final particle size of ultrafine POFA and the result shows that the size were within 1.4–1.8 µm. Previous studies revealed that the particles size of POFA affects the properties of concrete, the higher the fineness of POFA, the greater the pozzolanic properties [5][6].

2.1.3. Earth Clay Soil. The earth clay soil used in this study was extracted from a site near Faculty of Medicine & Health Sciences, Universiti Malaysia Sabah (UMS). The soil was extracted at 1.5 m deep because the top soil which contained organic matters are not suitable to be used as soil for bricks making.

2.2. Interlocking Compressed Earth Brick Mixture Design
Seven batch series of IC EB were made where the clay soil was partially replaced with 0%, 10%, 20%, 30%, 40%, 50%, and 60% of ultrafine POFA by weight. Table 1 shows the mixture proportions of the IC EB mixture. From Table 1, the water content of the mixtures was varied. This is because the optimum moisture content of every mixture is different. Further explanations are discussed in the experimental methodology section.

| Batch series | Cement (g) | Clay (g) | POFA (g) | Water (g) |
|--------------|------------|----------|----------|-----------|
| Control      | 250        | 2500     | 0        | 401.9     |
| CP10         | 250        | 2250     | 250      | 435.3     |
| CP20         | 250        | 2000     | 500      | 468.8     |
| CP30         | 250        | 1750     | 750      | 526.9     |
| CP40         | 250        | 1500     | 1000     | 550.0     |
| CP50         | 250        | 1250     | 1250     | 584.0     |
| CP60         | 250        | 1000     | 1500     | 591.2     |

C : Clay
P : POFA
10 : 10%
*CP10 : 10% of clay soil were replaced by POFA

2.3. Production of Interlocking Compressed Earth Brick
Cement, clay soil, and POFA were measured and mixed until a homogenous mixture was obtained. Measured water level was added gradually until the mixture was homogenous. After the mixing
process completed, the samples were poured into 50 × 50 × 50 mm of steel mould. Since this is just a preliminary assessment, 50 × 50 × 50 mm cubes were used to evaluate the compressive strength of all types of mixtures. The desirable mixture was then chosen for further investigation and experimental on the actual ICEB production. Each cube was first manually tampered using heavy steel tools before further compacting using the compression machine (universal testing machine). Six cubes were prepared for every mixture. After 24 hr of compaction, the specimens were dismantled from the mould and put into a tight covered container. Specimens were then cured for 7 and 28 days by water spraying method.

3. Experimental Methodology

3.1. Characterizations of Raw Materials. Chemical composition of cement, clay soil, and POFA were determined using x-ray fluorescence (XRF) spectrometry analysis. Scanning electron microscopy (SEM) analysis was used to generate high-resolution images of cement, clay soil, and POFA to investigate the structure and shape of the particles.

3.2. Soil Classifications. This test was carried out to determine the plastic limit (PL), liquid limit (LL), and the plasticity index (PI) of the clay soil in accordance to ASTM D4318 [7]. The method to identify the clay soil LL was conducted by cone penetrometer procedure while identification of PL was by hand rolling procedure. The PI was calculated using the result from LL and PL tests, where PI = LL−PL.

3.3. Standard Proctor Compaction test. This test was conducted to determine the optimal moisture content of the mixture when it became denser and achieved its maximum dry density. Proctor compaction test was conducted in accordance to ASTM D558 [8].

3.4. Compressive Strength test. All the specimens were tested for compressive strength at the curing age of 7 and 28 days by using universal testing machine (UTM). There were six samples for each batch series, three samples were tested for 7 days of curing age and three samples were tested for 28 days of curing age. An average value was obtained from the three results, which was the compressive strength of the mixture on specified age. This test is the main test method for this study, which was used to identify the suitable mixture design to produce ICEB that contained ultrafine POFA.

4. Results & Discussion

4.1. Characterizations of Materials

4.1.1. X-ray Fluorescence (XRF). Table 2 shows the chemical composition of cement, ultrafine POFA, and clay soil. The chemical compositions of cement were within the standard range of an OPC. According to ASTM C618 [9], a pozzolans should contained minimum 50.0% content of SiO₂ + Al₂O₃ + Fe₂O₃ for pozzolanic activity. The ultrafine POFA was categorised as Class C pozzolans. The summation of SiO₂ + Al₂O₃ + Fe₂O₃ content for POFA was 64.77% while in the standard stated that the minimum requirement of SiO₂ + Al₂O₃ + Fe₂O₃ for Class C pozzolans is 50.0% [9]. A good brick material should contain proper amount for silica as it will improve the durability of bricks. Generally, clay soil that are used for production bricks preferred to have SiO₂ that is within the range of 50%–60% [10]. It was observed that clay soil have higher silicon dioxide (SiO₂) (67.81%) content compared to the ultrafine POFA (59.77%). Other than that, if the composition of potassium oxide (K₂O), ferric oxide (Fe₂O₃), titanium dioxide (TiO₂), calcium oxide (CaO), and magnesium oxides (MgO) are
greater than 9%, the clay soil is classified as high refractory material. The clay soil used in this study has greater value of SiO$_2$ than the amount required. Moreover, it is classified as a high refractory material which means that it has high melting point [11].

**Table 2.** Chemical composition of cement, POFA and clay soil.

| Oxides component | Chemical composition (mass %) |
|------------------|-------------------------------|
|                  | Cement | POFA | Clay Soil |
| Silicon dioxide  | SiO$_2$ | 13.82 | 59.77 | 67.81 |
| Aluminium oxide  | Al$_2$O$_3$ | 3.60 | 1.80 | 20.61 |
| Ferric oxide     | Fe$_2$O$_3$ | 3.08 | 3.20 | 7.71 |
| Calcium oxide    | CaO     | 70.21 | 10.50 | 0.18 |
| Magnesium oxide  | MgO     | 1.84 | 7.24 | - |
| Potassium oxide  | K$_2$O  | 1.21 | 10.16 | 1.55 |
| Titanium dioxide | TiO$_2$ | 0.22 | 0.20 | 0.90 |

4.1.2. *Scanning Electron Microscope (SEM).* Figure 1 represents the SEM images of all raw materials used in this study. Figures 1(a) and 1(b) are the microscopic images of OPC and clay soil, respectively. It was observed that both materials exhibited almost the same structure, irregular shape with rough surface. Figure 1(c) represents the unground POFA. It was observed that the shape was almost sphere shape with high porosity structure. The microscopic image of ultrafine POFA is shown in Figure 1(d). As can be seen from the figure, there were huge differences in the reduction of size of POFA. Ultrafine POFA became irregular shape and reduced in the porosity structure.

4.2. *Classification of Soils*

The properties of soil tested is summarised in Table 3. The LL of the soil was 38.50% while the PL was 21.36%. Hence, the PI calculated was 17.15%. The PI results gives a measure of the plasticity of the clay soil used for classification [12]. According to ASTM C2487 [13], the result of PI investigated was in a highly plastic soils category and it is a clayey type of soil. It was reported that the soil with PI below 20% is good for cement stabilisation with cement content of 10% [14].

**Table 3.** Classification of soils

| Soil Properties    | Results               |
|--------------------|-----------------------|
| Liquid Limit       | 38.50%                |
| Plastic Limit      | 21.36%                |
| Plastic Index      | 17.15%                |
| Degree of Plasticity | Highly plastic        |
| Type of Soil       | Clayey Soil           |
Figure 1. SEM of raw material a) Cement b) Clay soil c) Unground POFA d) Ultrafine POFA

4.3. Optimum Moisture Content

Each of the batch series has different value of total moisture content. Hence, all the mixtures have different value of optimum moisture content. The initial moisture content of clay soil and ultrafine POFA was 3.75% and 1.32%, respectively. Figure 2 presents the optimum moisture content of all the mixture. Results showed that as the percentage of replacement increased, optimum moisture content was increased too. This might be due to the fine particle size of ultrafine POFA that promotes high surface area of the particles. Hence, it increased water demand to lubricate the floculated particles, to help in occupying all the voids of the combine mixture, to be denser and achieved the maximum dry density of the mixture [15]. Same observation was obtained by the author, when they replaced clay soil with quarry dust for brick production. Optimal moisture content increased as the percentage of replacement increased [16].
4.4. Compressive Strength

The result of compressive strength of the cubes containing ultrafine POFA is shown in Figure 3. It is observed that the strength of the control mixture at 7 days of curing age obtained a higher early strength compared to the other mixtures that contained ultrafine POFA as clay soil replacement. Referred to the error bar plotted on the graph in Figure 3, batch series CP20, CP30, CP40, CP50 and CP60 does not show significant difference in early strength while CP10 obtained slightly higher early age strength. The low early strength of mixture containing ultrafine POFA might be due to the delay in pozzolanic reaction of ultrafine POFA, which contributed to the production of secondary hydration products to make the harden specimen obtained denser structure [17]. As for the strength of cubes cured at 28 days, the control mixture obtained 13.44 kN/m$^2$ of strength. However, the strength started to decrease when 10% of clay soil was replaced with ultrafine POFA. From the Figure 3, 28 days strength was seen started to increase gradually from 20% of replacement to 50% of replacement. This might be due to the CaO and SiO$_2$ contents in ultrafine POFA, which were the fundamental for formation of calcium–silicate–hydrate (C-S-H) [18]. The SiO$_2$ reacts with the calcium hydroxide (Ca(OH)$_2$) generated by the hydration process of cement to form additional CSH to improve the binding with clay soil and create a denser structure [19]. In geotechnical engineering viewpoint, when ultrafine POFA was mixed with clayey soil, two reactions process occurred, (i) soil modification, which is the ion exchange reactions in the mixture between ultrafine POFA and clayey soil; (ii) soil stabilization, which is the pozzolanic reaction of ultrafine POFA and clayey soil, that helps to treat the chemical and physical features of clayey soils [20]. At replacement of 60%, the strength observed to have slightly decreased. This could be due to the reduction of cohesion caused by low clay content. Minimum amount of clay is required to assure a certain natural cohesion of the mixture [21]. The optimum clay content is found to be 15–30% that are more suitable in brick making [22]. Nevertheless, the strength obtained by mixture CP30, CP40, CP50, and CP60 was higher than the control mixture. This might be due to the pozzolanic properties of POFA which helps to promote the pozzolanic activity that contributes to the strength development [23][24]. With regard to the compressive strength properties, as shown in Figure 3, the most effective amount of ultrafine POFA content as a replacement for clay soil appeared to be approximately in a range of 30-60%.

![Figure 2. Optimum Moisture Content of all batch series.](image-url)
5. Conclusion

Based on this preliminary assessment, following conclusions can be drawn. The standard proctor compaction test indicates that the optimum moisture content of the mixture increases when ultrafine POFA content increased. Increment in the optimum moisture content is due to the effect of high fineness ultrafine POFA, whose surface area and texture are contradict with clay soil. A crucial finding of this assessment is that using ultrafine POFA as clay soil replacement to produce CSEB generally increases its compressive strength. The batch series CP50 obtained the highest compressive strength at 28 days of curing age, with 24.6% strength higher than the control mixture. Improvement of the compressive strength is due to pozzolanic reactions between the cement and ultrafine POFA. CaO and SiO$_2$ contents in ultrafine POFA contribute for formation of calcium–silicate–hydrate (C-S-H) to improve the binding with clay soil. By using POFA as a replacement of clay soil to produce ICEB, it will help to conserve our natural resources by preventing deforestation and clay mining activities. Hence, environmental problems can be solved.

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