Utilisation of palm oil fuel ash (Pofa) as sand replacement for fresh and hardened concrete by using powder and liquidation method

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Abstract. Palm oil fuel ash (POFA) is a waste material and generally disposed to open fields causing environmental pollution problems to the land and the air. Due to its abundance and high pozzolanic characteristics, it is highly potential to be used as civil engineering construction materials such as partial sand replacement in concrete. This paper presents the investigation of POFA as partial sand replacement in concrete. In doing so, two method of mixing processes were used namely powder and liquidation methods. The POFA was added in the concrete mix at various dosage levels of 0 %, 5 % and 10 % by weight of sand. Two types of testing were carried out; slump test for workability of fresh concrete identification and compressive strength test for strength identification of the hardened concrete cubes. The compressive strength test was carried out at 3, 7 and 28 days. The results from two different methods of mixing process were analysed, compared and discussed. From the results show that additional of 10 % of POFA by weight of sand is able to increase the strength of concrete at 28 days compared to other dosage levels. Hence, the POFA is given positive impact to be used as sustainable material in construction industry.

1. Introduction

Civil engineering industry is currently facing a critical problem in the production of concrete. It is because the concrete requires the use of natural resource such as sand. [10] stated that every year more than 10 billion tons of sand used results from the sand mining activity. In addition, this activity offers negative impact to the environment such as riverbank erosion, flood and river pollution. Since demand for the utilization of sand in concrete industry, an alternative material must be used to replace sand as partially or fully replacement. The characteristic of that material should be similar with the characteristic of sand such as silica. One of the materials is palm oil fuel ash (POFA), which it is a waste material from combustion of palm oil industry.

POFA has been used as cementitious material in concrete [7][9][14] and as lightweight material in production of lightweight concrete [8][12]. Recently, the use of POFA in concrete has been reviewed by [6]. Some highlights have been addressed. They found that the POFA is able to react well with the other constituent materials and hence able to produce stronger concrete. At the same time, the silica
(SiO₂) content in POFA is able to increase the compressive strength of concrete and able to reduce the water absorption. Moreover, the comparison the use of POFA and sand has been done. From the review they found that the 10 to 20 % of POFA as filler in lightweight foamed concrete improves the compressive strength, flexural strength and tensile strength compared to foamed concrete containing sand only. From the review indicates that the POFA can be used extensively as partially or fully sand replacement to the concrete [11] stated that the SiO₂ composition in POFA is 71.20 %. [14] found that the SiO₂ in POFA is 65.32 %. Due to composition of SiO₂ in POFA, an investigation has been carried out by [5] on the effect of POFA as partial replacement of cement in mortar mix. They found that the compressive strength of mortar increased to 15 % at 7 and 28 days of treatment. Moreover, the drying shrinkage is found to be decreased to 7.5 %. POFA has also been used as partial cement replacement in mortar mix at various dosage levels of 0 to 90 % of cement weight by [14]. They found that the POFA increased the compressive strength of mortar, however, the strength reduced if the dosage level of 40 % and above has been added in the mortar mix. From investigation carried out by [1] on the performance of green engineered cementitious composites (ECC) specimen containing POFA, found that the treated POFA has 66.91 % SiO₂. Due to this factor, the flexural deflection capacity of the ECC specimen increased. From the review found that the POFA has been used extensively as cementitious material in mortar and concrete. One of the reasons is due to high composition of SiO₂ in POFA. However, the use of POFA as sand replacement is still limited assesses. In general, the SiO₂ content in sand is 99.2 % [1]. From this composition of SiO₂, it indicates that the POFA is potentially used as fully or partially sand replacement in concrete mix. Hence, this paper presents the investigation of POFA in concrete mix using two different types of mixing processes. The mixing processes would be carried out was based on the liquidation method and powder method.

2. Experimental Programme

2.1. Preparation of materials

In this study, the concrete was designed as concrete grade C30 with composition of cement, water, sand and coarse aggregate. Mix proportion of the concrete is presented in Table 1. The POFA was added in the concrete mix as partial sand replacement at various dosage levels of 0, 5 and 10 % of the weight of sand. The POFA was supplied by United Oil Palm Industries Sdn. Bhd., Nibong Tebal, Pulau Pinang. It was dried in oven at temperature of 100 °C at 24 hours to remove the moisture content in the POFA. The chemical composition of the POFA is presented in Table 2. Then, it was sieved in order to have maximum size of 212μm. Constant cement to water ratio of 0.5 was used throughout the concrete mix. Moreover, constant proportion of coarse aggregate was also used. In order to have accurate measurement, all materials were weighed using Electronic Balance Weighing Scale Machine.

| Mixing process | Designation | Cement (kg) | Water (kg) | Sand (kg) | POFA (kg) | Sand : POFA (%) | Coarse aggregate (kg) |
|----------------|-------------|-------------|-----------|-----------|-----------|-----------------|-----------------------|
| Control        |             | 470         | 235       | 895       | 0         | 100 : 0         | 790                   |
| Powder method  | PM5         | 470         | 235       | 850       | 45        | 95 : 5          | 790                   |
|                | PM10        | 470         | 235       | 805       | 90        | 90 : 10         | 790                   |
| Liquid method  | LM5         | 470         | 235       | 850       | 45        | 95 : 5          | 790                   |
|                | LM10        | 470         | 235       | 805       | 90        | 90 : 10         | 790                   |

Table 1. Mix proportion of concrete mixes in kg/m³.
In the preparation of the concrete containing POFA, two types of mixing processes were used namely liquidation and powder methods. For the powder method, the technique of mixing was carried out in accordance with BS 1881-125 [4]. Meanwhile, the liquidation method was based on trial. The trial was carried out until the mixing gave the best mixture. For both mixing processes, they were designated as presented in Table 1. In the table, PM indicates the mixing process using powder method and LM using liquidation method.

| Designation | Water mixes in POFA (kg) | POFA (kg) | Water/POFA |
|-------------|-------------------------|-----------|------------|
| LM5         | 67                      | 45        | 0.67       |
| LM10        | 134                     | 90        | 0.67       |

2.2. Testing of the fresh concrete and hardened concrete cubes

Slump test was performed to measure the workability of the fresh concrete. The procedure was carried out in accordance with BS EN 12350-2 [2]. Figure 1 shows the slump test conducted in this study. In
total, five slump tests were performed. The steel slump cone was placed on the smooth horizontal base plate. The slump cone was filled with the fresh concrete mix in three equal layers. Steel rod of 16 mm was used to tamp the concrete in the slump cone. Each layer of the concrete was tamped with 25 strokes in a uniform manner as shown in Figure 1a). For the last layer, the remaining concrete was removed and leveled the surface using trowel. The slump cone was slowly raised in vertical direction from the concrete. Then, the slump height was measured using ruler as shown in Figure 1b.

![Figure 1](image1.png)

**Figure 1.** a) The tamping of the concrete in slump cone. b) Measurement of the slump height.

In order to determine the strength of the hardened concrete cubes, the compressive strength test was conducted. The test was based on BS EN 12390-3 [3]. It was performed for the concrete cubes at the age of 3, 7 and 28 days. Test set up of the cube is shown in Figure 2. Prior to carry out the testing, the cubes were firstly cleaned and dried at the temperature room. The weight of the cubes was measured before testing. A pace rate of 3.0 kN/s was used throughout the test.

![Figure 2](image2.png)

**Figure 2.** Set up for the compressive strength test.

### 3. Results and Discussion

#### 3.1. Slump results of the fresh concrete

Figure 3 shows the slump test results of fresh concrete at different concrete mixes. From the figure, it is found that the concrete mix for control represents the highest slump compared to concrete containing POFA at various dosage levels. The slump height for control is 65 mm was in the range of concrete design of 60 mm to 180 mm. However, concrete mix using liquidation method represents the highest slump compared to powder method. The slump for LM5 and LM10 is found to be 55 mm and 50 mm, respectively. In this study, the slump height for powder method is 42 mm and 35 mm for PM5
and PM10, respectively. It indicates that the liquidation method would give good workability to the fresh concrete.

At the same time, the dosage levels affect to the workability of the fresh concrete, where the higher the dosage level of the POFA in the concrete mix, the lower the workability would be presented. It is noticed that the percentage reduction for the concrete containing POFA as partial replacement using powder method was 16.7 %. Meanwhile for the concrete containing POFA as partial sand replacement using liquidation method, the percentage reduction was 9.1 %. This reduction is due to the properties of POFA which is high porosity where it can absorb more water in the concrete mix [10]. Moreover, the POFA is finer than sand, hence acquiring larger surface area in the concrete mix.

![Figure 3](image_url)

**Figure 3.** Slump height of the fresh concrete for different types of concrete mix.

### 3.2. Compressive strength of the hardened concrete cubes

The strength of the concrete prepared with the different dosage levels of POFA as partial sand replacement for 3, 7 and 28 days as shown in Figure 4. It is found that the LM5 represents the highest strength with the value of 34.57 MPa at 3 days compared to other samples. However, the lowest strength was LM10 with the value of 28.6 MPa. From this early strength of concrete, it shows that liquid method contains POFA as partial sand replacement with dosage level of 5 % of sand weight is able to increase the strength of the concrete compared to control sample. It is due to C-S-H gels in the POFA generates bonding between aggregates and cement which contributes to the increment of concrete strength [15]. At the same time, the fine particle in POFA is beneficially used as a filler to fill the void in the concrete [16]. Hence it would increase dense of the concrete, which induces its strength. In contrast, liquid method with dosage level of 10 % POFA contributes the lowest strength to the concrete performance. It can be inferred that concrete containing POFA at various dosage levels and mixing methods would increase the strength of concrete.

At 7 days, the LM5 represents the highest compressive strength compared to other samples with the value of 42.41 MPa. However, the PM5 exhibits the lowest compressive strength of 32.81 MPa. Nevertheless the strength of control is found higher than the concrete containing 5 % POFA as partial sand replacement. In general the concrete containing POFA improve the compressive strength at 7 days.

At 28 days, the powder method produced the higher strength than liquidation method at different dosage of POFA in concrete. The result shows at the age of 28 days for control, PM5, LM5, PM10 and LM10 were 46.78MPa, 49.71MPa, 46.07MPa, 52.28MPa and 49.05MPa, respectively. It is found that, the concrete with 10% POFA by using powder method produces the highest strength compared to other samples. However, most of the concrete with POFA has higher strength than the control. It indicates that the concrete containing POFA was produced the best compressive strength. Similar findings have been found by [13] on the strength of concrete. Hence, the POFA can be used as a material in construction industry as partial sand replacement in concrete.
Figure 4. Compressive strength with respect to days of the concrete cubes.

Table 4 shows the strength effectiveness of the concrete containing different dosage levels of POFA results from comparing with control sample. In this study, the dosage of 5% POFA using liquidation method in concrete represents the highest strength effectiveness of 16.79% and 21.52% at 3 and 7 days, respectively. However, at 28 days, the powder method represents the highest strength effectiveness compared to liquid method with the dosage level of 10%. The strength effectiveness is 11.76%. It can be summarised that at early strength, liquidation is performed well to increase the strength of the concrete. However, the maturity age of concrete as well as 28 days, the powder method is more effective compared to liquidation method.

Table 4. Strength effectiveness of the concrete containing POFA as partial sand replacement.

| Samples | Strength effectiveness, % |
|---------|---------------------------|
|         | Days                       |
|         | 3  | 7  | 28  |
| PM5     | 2.67 | -5.99 | 6.26 |
| LM5     | 16.79 | 21.52 | -1.52 |
| PM10    | 11.35 | 12.38 | 11.76 |
| LM10    | -3.38 | 4.7  | 4.85 |

4. Conclusion

In a nutshell, the workability and compressive strength of concrete containing POFA as partial sand replacement with different dosage levels of POFA were presented. The compressive strength test was carried out on the hardened concrete at 3, 7 and 28 days.

It can be inferred that the liquidation method produced good workability whether in low dosage or high dosage of POFA. As compared to powder method, the result of workability resulted low in both dosage.
The highest compressive strength achieved for this study resulted powder method as the highest with dosage of 10% POFA as partial sand replacement which is 52.28 MPa at day 28.

It is noticed that the percentage reduction for the concrete containing POFA as partial sand replacement using powder method was 16.7%. Meanwhile for the concrete containing POFA as partial sand replacement using liquidation method, the percentage reduction was 9.1%.

All these findings begin to highlight that there is possibility that the palm oil factory could finally manage to put use of this by-product as one of the money generating element that definitely able to contribute extra income to the company besides being a more environmental friendly industry. It is hoped, this finding will encourage other researchers to discover more ways to make use the industrial or agricultural by-product for the benefits of mankind.

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