Properties of Mortar Containing High Volume Palm Oil Biomass Waste

Nor Hasanah Abdul Shukor Lim¹,a, Mohd Warid Hussin²,b*, Abdul Rahman Mohd. Sam³,c, Muhammad Aamer Rafique Bhutta⁴,d, Nur Farhau Ariffin¹,e, Nur Hafizah Abd Khalid¹,f, Mostafa Samadi¹,g

¹Postgraduate student, Construction Material Research Group (CMRG), Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
²Professor, Construction Research Centre (UTM CRC), Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
³Associate Professor, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
⁴Postdoctoral Fellow, Department of Civil Engineering, Faculty of Applied Science, University of British Columbia, Vancouver, British Columbia, V5P 1X6, Canada

a amoi_1464@yahoo.com, b warid@utm.my*, c abdrahman@utm.my, d aamer.bhutta@gmail.com, e farhau_rui@yahoo.com, f fiza_johor2003@yahoo.com.sg, g kouchaksaraei@yahoo.com

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Abstract. The utilization of waste materials which are abundant and cheap, especially from clean resources, has become more pressing than ever. This paper, discusses the utilization of the wastes in the form of palm oil fuel ash and oil palm kernel shell in the production of mortar mixes as a part of new and innovative materials in construction industry. The studies include the basic properties including the morphology of the composite with regards to variations in the mix design process. In order to get a better performance in terms of strength development, the ash used has gone through heat treatment and ground up to the size less than 2μm. High volume of 60%, 80% and 100% palm oil fuel ash was used as cement replacement. The incorporation of more than 80% of palm oil biomass waste as cement and sand replacement has produced mortar having an improved compressive strength than normal mortar. In addition, the density of the mortar with biomass waste was less than normal mortar. Overall results have revealed that the inclusion of high volume palm oil biomass waste can produce mortar mix with high strength, good performance and most importantly more sustainable.

Introduction

Oil palm biomass waste is fast turning into a highly prized commodity in Malaysia. These would be a significant contribution to the country’s gross national income of about RM30 billion by 2020 via full utilization of the palm oil industry by-product such as the empty fruit bunches, shells, mesocarp fibre, felled tree fronds and trunk as well as palm oil mill effluent [1]. The local palm oil sector generates an estimated 80 million tonnes of biomass in 2010 and is expected to increase to about 100 million tonnes by 2020, primarily due to increases in yields. From the oil palm waste, more downstream operations such as the production of wood products, pellets, bio-energy, biofuel and bio-based chemicals can be created [2]. Towards higher human development and sustainable economic growth, affordable products with advance properties are need. Thus, the utilization of waste materials which are abundant, especially from clean resources, has become more pressing than ever especially palm oil biomass waste.

It is estimated that the total potential palm oil biomass from 4.69 million hectares of palm oil planted area in Malaysia in 2009 is 77.24 million tonnes per year comprising 13.0 million tonnes of Oil Palm Trunks (OPT), 47.7 million tonnes of Oil Palm Fronds (OPF), 6.7 million tonnes of...
Empty Fruit Bunches (EFB), 4.0 million tonnes of Palm Kernel Shell (PKS) and 7.1 million tonnes of Mesocarp Fibre (MF) [3,4]. These biomasses are still often used as boiler fuel by palm oil mill plants to produce steam for electricity generation [5] and after combustion in the steam boiler there is approximately 5% of ash being produced [6] and generate another solid waste. POFA is an abundant agricultural by product from palm oil industries in Malaysia. This biomass waste ash which is the source of siliceous material is produced after the combustion of palm oil fibre, shell and mesocarp as boiler fuel to produce steam for palm oil mill consumption [7].

POFA which is an agricultural waste and one of the pozzolanic materials as studied by previous researchers and has been successfully used in the improvement of strength and durability of mortar when properly processed [8,9,10]. Although there are some studies on the utilization of POFA such as cement replacement material [11,12], most of the ash is still disposed off in landfill that requires a lot of land area which finally caused environmental problems and without any economic return [13]. Majority of these studies were conducted on ashes obtained directly from palm oil mills to establish the pozzolanic activity and suitability of POFA as binders after grinding [14-16]. Normally, the POFA contains high amounts of unburned matter, silicon, and aluminum. In general, unground POFA is black in colour because of the unburned carbon content due to a relatively low burning temperature. However, the colour becomes dark gray in the case of ground POFA [17].

Materials

Palm Oil Fuel Ash (POFA).

The POFA used in this study were black in colour obtained from palm oil mill located in Johor which is southern part of Malaysia. The POFA was dried in oven for 24 hours at 105°C and sieved passing through a 150 µm sieve to remove coarser particles. Before further treatment the loss on ignitions (LOI) of the POFA was 20.9%. The POFA was then heated to 500°C for 1 hour in a furnace to remove the excessive unburned carbon [18,19]. The unburned carbon is the most significant factor to be considered because it will cause an increase of water and super plasticizer (SP) requirement in the mix [14, 18]. Then it was subjected to further grinding using ball mill until average size of less than 2 µm. Therefore, in order to ensure the uniformity and consistency of the resulting POFA, necessary measures were taken to control the treatment process which include the grinding time, mass of POFA fed into the ball mill, milling speed, thickness of POFA layer in the furnace during heat treatment and the duration as well as the temperature of heat treatment [19]. The chemical composition of OPC and POFA used in this study are shown in Table 1. The findings show that the POFA used is classified as Class F pozzolan according to ASTM C618-05 [20], and similar to the observations made by previous research [21].

<table>
<thead>
<tr>
<th>Chemical composition (%)</th>
<th>OPC</th>
<th>POFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>16.40</td>
<td>69.3</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>4.24</td>
<td>5.30</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.53</td>
<td>5.10</td>
</tr>
<tr>
<td>CaO</td>
<td>68.30</td>
<td>9.15</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.22</td>
<td>11.10</td>
</tr>
<tr>
<td>MgO</td>
<td>2.39</td>
<td>4.10</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>SO₃</td>
<td>4.39</td>
<td>1.59</td>
</tr>
<tr>
<td>LOI</td>
<td>2.4</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Oil Palm Kernel Shell (OPKS).

The collected OPKS was subjected to further grinding to obtain similar properties as sand. The use of OPKS was to reduce the density of high volume palm oil biomass mortar. The bulk density of OPKS and sand used were 750kg/m³ and 1614kg/m³, respectively. The size used was in the range of 300µm – 2.35mm. The sieve analysis of OPKS and fine aggregate used is shown in Fig. 1. The upper and lower limits were derived according to ASTM C33-03 [22].

![Sieve analysis for fine aggregate](image)

Figure 1. Sieve analysis for fine aggregate

### Test Methods

#### Preparation of specimens.

All mortar specimens were prepared with blended ash to fine aggregate ratio of 1:3, whereby the fine aggregate was prepared in ambient air dry condition. The mixing was carried out in a room temperature of approximately 28°C. The mix proportions for all mixes are given in Table 2. The cube test specimens of 70x70x70 mm were prepared. The specimens were compacted in two-layer with tamping as described in ASTM C109-11 [23]. The specimens were demoulded after 24h and placed in water tank for curing process until the age of testing.

<table>
<thead>
<tr>
<th>Materials</th>
<th>OPC (kg/m³)</th>
<th>60% POFA</th>
<th>80% POFA</th>
<th>100% POFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPKS</td>
<td>1578</td>
<td>1578</td>
<td>1578</td>
<td>1578</td>
</tr>
<tr>
<td>w/c ratio</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table 2. Mix proportions of biomass mortars
Determination of Workability and Strength.

The workability in terms of flow and compressive strength were studied in accordance with ASTM C230-08 [24] and ASTM C 109-11 [23], respectively. The specimens cured in water were tested for 7, 14 and 28 days for compressive strength test. Three specimens were tested to obtain the average value for each test condition.

Results and Discussions

Morphological Structure of POFA.

The morphological structure of POFA sample was examined using Field Emission Scanning Electron Microscope (FESEM) technique. A typical electron micrograph of the ash is shown in Fig. 2. It can be seen from the figure that the particle of POFA generally spherical, but also consists of irregular, thinner and crushed particle [11,12].

Workability of mortar.

The level of workability of all mortar mixes is illustrated in Fig. 3. It can be seen that the flow values for OPC is 140mm and for POFA replacement levels of 60, 80 and 100% by weight are 110, 100 and 90mm, respectively. The result shows that higher replacement of cement with POFA required higher water demand compared to OPC mortar. Furthermore, this is due to the fineness particle of POFA that have larger surface area [25].

![Figure 2. Scanning electron microscope of POFA](image)

![Figure 3. Flow result of high volume POFA mortar](image)
Effect of high volume POFA in mortar.

The effect of high volume of POFA on strength performance is shown in Fig. 4. As the percentage of POFA increase, the compressive strength of mortar was decreased. This probably due to the lack of calcium hydroxide to react with reactive silica from POFA resulting in less calcium silicate hydrate gel (CSH) [25]. The compressive strength of mortar increased as the age increased due to the hydration process that cause in increased of the CSH gel. In addition, it is believe that the finer particles will fill the void inside the mortar and makes it denser than normal OPC mortar. Similar findings also reported by previous researcher [26]. The strength of POFA mortar is expected to be higher at later ages due to its pozzolanic reaction activities that resembles with other blended cement mortar behaviour. In this study, 80% of POFA was selected because of the main aim is to use high volume of cement replacement. Total replacement of cement using POFA is not feasible because of lack of Calcium Hydroxide that will react with reactive silica resulting in lower compressive strength.

![Figure 4. Effect of high volume POFA on compressive strength of mortar](image)

Effect of OPKS in mortar.

The effect of percentage of OPKS on compressive strength of mortar is shown in Fig. 5. The cement was substituted by 80% of POFA in all the mortar mixes. The sand was replaced with 25, 50, 75 and 100% of OPKS. With the increasing of OPKS percentage, the compressive strength was decreased. This is due to the properties of OPKS which is derived from palm oil biomass waste as reported by other researcher that the strength, thickness and density of OPKS are lower than those of sand which are the governing factors for the compressive strength in mortar. On their account, the irregular shape of OPKS is one of the factors for strength. They also reported that compressive strength is controlled by both the strength of the aggregate and the strength of paste, and depends on one of these two that fails first [27].
Fig. 5 represents the comparison between OPC, high volume POFA mortar and palm oil biomass waste mortar. It can be seen from the figure that at early age OPC mortar shows higher strength than others. However, the high volume POFA mortar and biomass mortar show higher compressive strength at 28 days which is 34 and 36 MPa, respectively. This is due to the pozzolanic reaction derived from POFA with the calcium hydroxide to produce more calcium silicate hydrate gel and make the mortar denser similar to the finding from other researcher [25].

**Conclusion**

The conclusions that can be drawn from this study is that high volume POFA with some modification can be used up to 80% as cement replacement and achieve higher strength than OPC mortar at later age. The fineness of POFA which is less than 2 µm gives better effect to the mortar both as binder and filler. The use of OPKS as sand replacement can reduce the density of mortar with comparable strength of the OPC mortar. More than 80% waste from palm oil biomass can be used to produce mortar with better strength than normal mortar.
Acknowledgements

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