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The Effect of Oil Palm Kernel Shell in Producing Different Types of POFA Based Mortar

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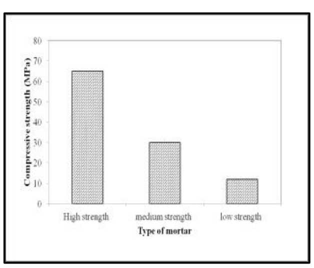
Graphical abstract



Abstract

This paper presents the utilization of palm oil fuel ash and oil palm kernel shell as cement and sand replacement, respectively in the production of palm oil fuel ash based mortar mixes as part of new and innovative materials in the construction industry. The study includes basic properties such as water absorption, density, compressive strength, and microstructure test with regards to variations in the mix design process. In order to get better performance in terms of strength development, the ash used was subjected to heat treatment and grounded to the size of less than 2 µm. High volume of 80% palm oil fuel ash was used as cement replacement, while 25%, 50%, 75%, and 100% of oil palm kernel shell was used as sand replacement. The results indicated that the density of the mortar decreases with increasing volume of oil palm kernel ash as sand replacement. Three different types of mortar were produced with different percentages of oil palm kernel shell, which was high strength, medium strength, and low strength lightweight mortars.

Keywords: Biomass waste, oil palm kernel shell, density, lightweight

1.0 INTRODUCTION

Nowadays, the growing usage of natural aggregate for producing concrete and mortar disturbs the natural resources and causes heavy stress to the environment. Therefore, the utilization of waste materials has been a great concern recently. The public's concerns on environmental issues and sustainable development have encouraged researchers to utilize industrial or agricultural waste in concrete or mortar.

Growing agricultural production all over the world has produced a large amount of agricultural wastes, which are not fully utilized. These wastes have been used for animal feed, fertilizer, and fuel for energy production [1]. However, researches on how to apply agricultural waste in building construction are limited. Besides, the shortage of natural resources and increasing cost of transportation encourages the use of waste materials, which are available near the construction sites.

Annually, about 4 million tons of Oil Palm Kernel Shell (OPKS) are produced in Malaysia [2] and it is expected that around 5 million hectares (ha) of palm oil trees will be planted by the year 2020 [3]. Malaysia is the second largest producer of crude palm oil in the world, consequently producing a large amount of palm oil waste.

Many researchers focus on the utilization of OPKS as lightweight aggregate to reduce the harmful effect of this waste on the environment [4, 5]. However, there is a lack of information on using OPKS as fine aggregate replacement. Therefore, the effect of OPKS as fine aggregate replacement in producing different types of mortar has been investigated and reported in this paper. The basic properties of OPKS were determined through the sieve analysis test, shape, and size determination and bulk density test.

2.0 EXPERIMENTAL

2.1 Materials

2.1.1 Palm Oil Fuel Ash (POFA)

The POFA used in this study were black in colour, obtained from the palm oil mill located in Johor, Malaysia. The POFA was dried in the oven at a temperature of 105±5°C for 24 hours and then, the coarse particle of POFA was removed by sieving with sieve size 150 µm. The POFA was heated to 500°C for one hour in a furnace to remove the excessive unburnt carbon [6]. The unburnt carbon is the most significant factor to be considered because it may lead to increase in water and super plasticizer requirement in the mix [7]. Then, it was subjected to further grinding using the ball mill until it reaches an average size of less than 2 µm [8]. The chemical composition of OPC and POFA used in this study are shown in Table 1. The findings shows that the POFA used was classified as Class F pozzolan according to ASTM C618-05 where the combination of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3) where more than 70%.

2.1.2 Oil Palm Kernel Shell (OPKS)

The collected OPKS was subjected to further grinding to obtain similar properties as sand. The bulk density of OPKS and sand used were 750 kg/m^3 and 1614 kg/m^3, respectively. The size used was in the range of 300 µm – 2.35 mm.

Table 1 Chemical composition of OPC and POFA

Chemical composition (%)	OPC	POFA
SiO_2	16.40	69.3
Al_2O_3	4.24	5.30
Fe_2O_3	3.53	5.10
CaO	68.30	9.15
K_2O	0.22	11.10
MgO	2.39	4.10
CO_2	0.10	0.10
SO_3	4.39	1.59
LOI	2.4	1.3

Figure 1 Waste OPKS in the landfill

Figure 1 shows the OPKS being dumped at the factory yard after the extraction of the oil palm. Figure 2 shows the shape and size measurement of OPKS used in the research. The OPKS aggregate shape is angular and flaky. The method used in the breaking process of palm oil fruits has an effect on the shape of aggregate [4]. The species of palm oil fruit have an effect on the thickness of OPKS between 0.15 and 8 mm [9].

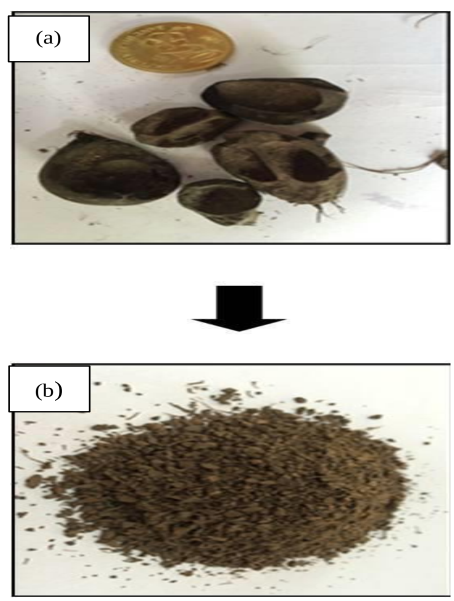


Figure 2 Shape and size measurement of OPKS used (a) coarse OPKS (b) fine OPKS

The sieve analysis of OPKS and fine aggregate used is shown in Figure 3. The upper and lower limits were derived according to ASTM C33-03.

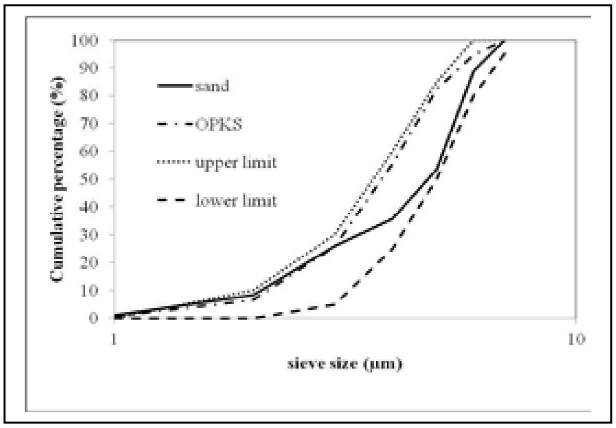


Figure 3 Sieve analysis for OPKS and sand

2.2 Sample Preparation

All mortar specimens were prepared with binder to fine aggregate ratio of 1:3, whereby the fine aggregate was prepared into saturated surface dried condition. For this paper, 80% POFA was used as cement replacement for all mixes. The mixing was carried out at room temperature of approximately 28±2°C [10]. The mix proportions are given in Table 2. Test specimens of 70 x 70 x 70 mm cubes were prepared and the specimens were compacted in two layers with rod tamping as described in ASTM C109-13. Additional vibration of about 10s was applied using the vibrating table. The test specimens were cured in water for 7, 14, and 28 days.

The compressive strength was studied in accordance to ASTM C 109-11. Three specimens were tested to obtain the average value for each test condition**.** The microstructure of mortar was investigated using Field Emission Scanning Electron Microscopy (FESEM). The surface of the specimens obtained from the compressive strength test was coated with gold prior to morphological observation. The water absorption of mortar was determined in accordance with ASTM C140-14. The test was conducted at 28 days after curing in water.

Table 2 Mix proportion of mortar

Materials (kg/m3)	**Mortar mix**				
	OPC	25% OPKS	50% OPKS	75% OPKS	100% OPKS
Cement	105	105	105	105	105
POFA	420	420	420	420	420
Sand	1578	1183	789	395	-
OPKS	-	395	789	1183	1578
w/c ratio	0.4	0.4	0.4	0.4	0.4

3.0 RESULTS AND DISCUSSION

3.1 Density

The relationship between compressive strength and density of mortar is shown in Figure 4. From the Figure, it can be seen that the use of OPKS helped in reducing the density of mortar because OPKS has lower specific gravity than normal sand.

This is advantageous since it has a lot of finer material that increases the density of mortar. The relationship between the compressive strength and density, as shown in Figure 4, follows a linear pattern. The coefficient of determination (R^2) value of 95% shows a good prediction of the relationship.

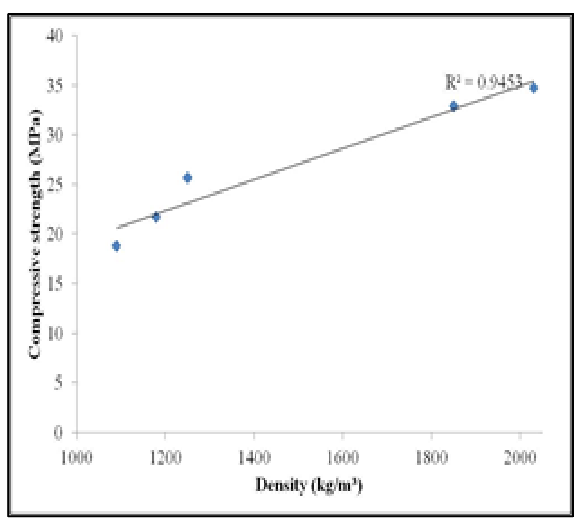


Figure 4 Relationship between compressive strength and density

3.2 Effect of OPKS on Compressive Strength

The effect of percentage of OPKS on compressive strength of mortar is shown in Figure 5. The sand was replaced with 25, 50, 75 and 100 % of OPKS. With the increasing OPKS percentage, the compressive strength decreased. This is due to the properties of OPKS, which was derived from palm oil waste as reported by other researcher [4]. The compressive strength of the mortar was affected by the strength, thickness, and density of OPKS aggregate.

The OPKS have flaky shape which causes reduction in strength of the mortar. Besides, the aggregate strength and binder strength were important factors in reducing the compressive strength [11].

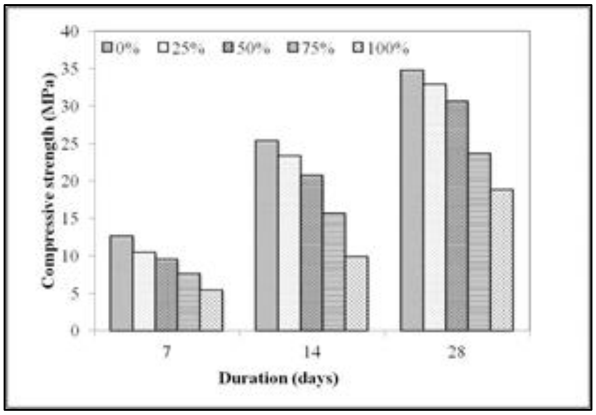


Figure 5 Effect percentages of OPKS on compressive strength of mortar

3.3 Water Absorption

The water absorption of POFA based mortar is shown in Figure 6. The percentage of water absorption increases as the percentage of OPKS increase. This was due to the porous surface of OPKS that tend to absorb more water during mixing [5]. Previous researchers have mentioned that the average water absorption for OPKS mortar varied between 14-33 % [12]. However, the result shows that the water absorption was less than 10%. This is due to the high volume of POFA used in the mortar that made the mortar more dense and durable.

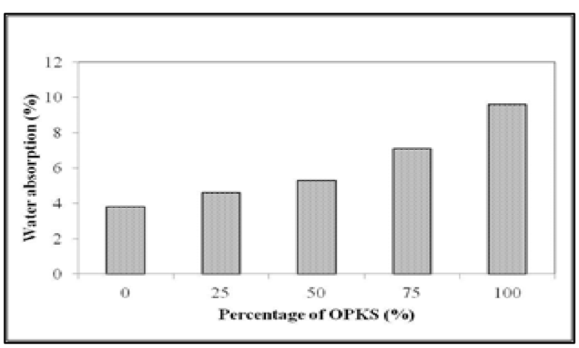


Figure 6 Water absorption of mortar with different percentage of OPKS

Meanwhile, Figure 7 shows the relationship between water absorption and compressive strength of mortar. The R^2 value was 98% for the linear equation. The compressive strength of mortar increases with decrease in water absorption due to less porosity inside the mortar.

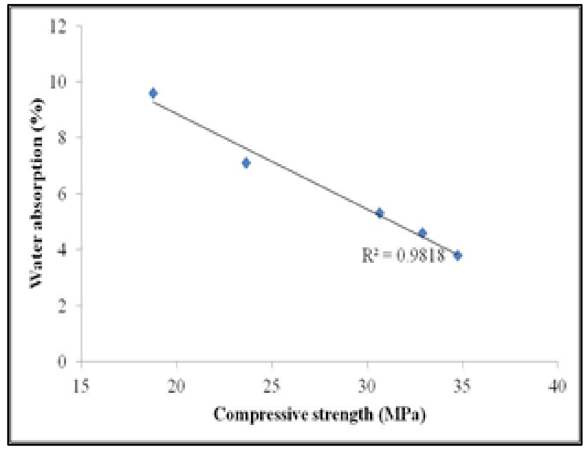


Figure 7 Relationships between water absorption and compressive strength of mortar

3.4 Microstructural Analysis

Figure 8 shows the morphology of POFA based mortar with 50% and 100% replacement, respectively. The morphology was determined using a FESEM machine. From the Figures, the 50% replacement of OPKS shows the existence of more bonding between binder and fine aggregate. This was due to the calcium silicate hydrate gel from the reaction between POFA and cement [13]. Besides, OPKS also contributed to some silica content which increases the pozzolanic reaction.

Obviously, the presence of higher silica content influences the pozzolanic reaction to produce extra calcium silicate hydrate gel, thus making the mortar more durable and denser [14]. However, with the addition of 100% OPKS, the reaction reduced, thus decreasing the compressive strength of the mortar. This could be due to the excessive amount of filler and the flaky shape of OPKS [15]. Besides, the compressive strength of OPKS also depends on the bond between the fine aggregate and the strength of OPKS itself [4, 16].

3.5 Type of Mortar

Figure 9 shows different types of mortar produced with different percentage of OPKS at 28 days. With 50% replacement, the strength was 30MPa and comparable with conventional mortar, but with lower density. Therefore, this would help to reduce the material cost of construction by approximately half compared to the normal cost. The density of the low strength mortar produced was 1090kg/m³ and it is within the range for lightweight mortar according to

BS EN 998-1, where the required dry hardened density of mortar is less than 1300kg/m^3. By using different percentages of OPKS, three types of mortar can be produced for different types of applications.

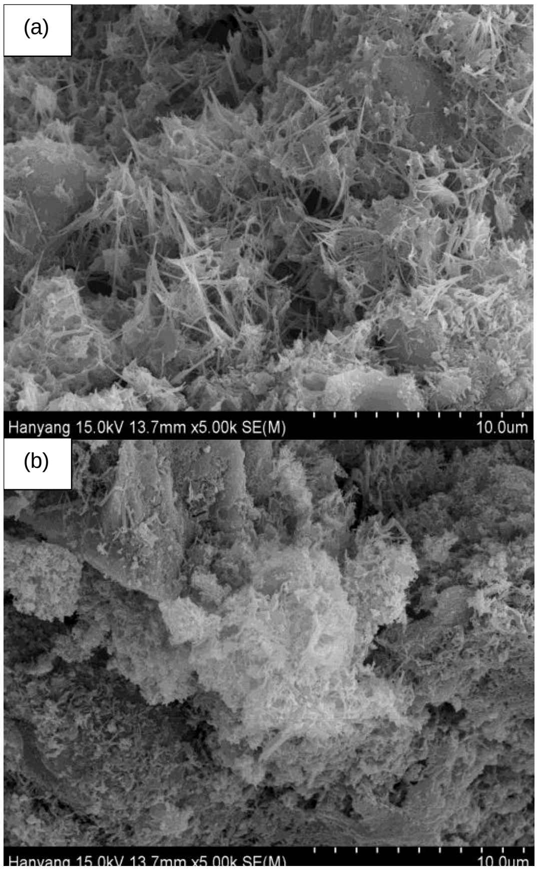


Figure 8 Different type of mortar produces with effect of OPKS (a) 50% OPKS (b) 100% OPKS

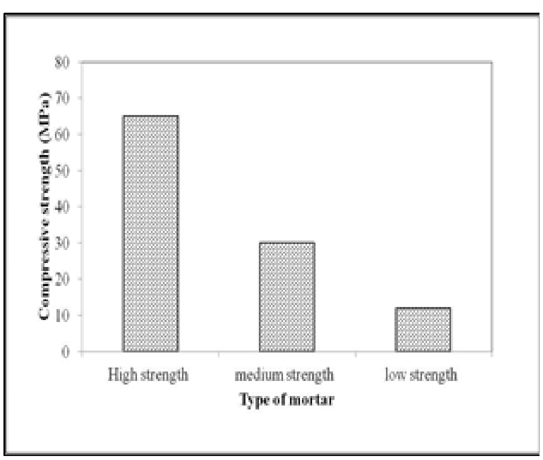


Figure 9 Different type of mortar produces with effect of OPKS

4.0 CONCLUSION

Based on the test results obtained, it can be concluded that POFA can be used for up to 80% replacement of cement. The compressive strength of mortar was improved by using fine OPKS compared to coarse OPKS. Different percentages of OPKS can be used to produce various types and degrees of mortar, which can be classified as high strength, medium strength, and low strength lightweight mortars.

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