

Palm Oil Fuel Ash (POFA) and Eggshell Powder (ESP) as Partial Replacement for Cement in Concrete

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Abstract. This study is an attempt to partially replace Ordinary Portland cement (OPC) in concrete with palm oil fuel ash (POFA) and eggshell powder (ESP). The mix proportions of POFA and ESP were varied at 10% of cement replacement and compared with OPC concrete as control specimen. The fineness of POFA is characterized by passing through 300 μm sieve and ESP by passing through 75 μm sieve. Compressive strength testing was conducted on concrete specimens to determine the optimum mix proportion of POFA and ESP. Generally the compressive strength of OPC concrete is higher compared to POFA-ESP concrete. Based on the results of POFA-ESP concrete overall, it shows that the optimum mix proportion of concrete is 6%POFA:4% ESP achieved compressive strength of 38.60 N/mm² at 28 days. The compressive strength of OPC concrete for the same period was 42.37 N/mm². Higher water demand in concrete is needed due to low fineness of POFA that contributing to low compressive strength of POFA-ESP concrete. However, the compressive strength and workability of the POFA-ESP concrete were within the ranges typically encountered in regular concrete mixtures indicating the viability of this replacement procedure for structural and non-structural applications.

1 Introduction

Concrete plays a crucial role in developing the infrastructure of all nations. Nowadays, sustainable construction has gradually become a topic of interest in the engineering as well as other fields. Ordinary Portland cement (OPC) is generally used as a binding material while granite and mining sand are used as aggregate in regular concrete mixes. The production of OPC causes carbon dioxide (CO₂) emissions. As a result, carbon dioxide gas emissions cause harm and pollute the environment. Many research studies have been carried out on utilising the wastes from generated by the industry as cement replacement in the construction industry [1 – 4].

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Palm oil fuel ash (POFA) is one such waste. It is a recycled material that originates from the palm oil industry. POFA is the ash that is produced in the plant boiler by burning the oil palm shell (OPS), and empty fruit bunches (EFB) [5]. According to Pakiam [6], Malaysia is said to be one of the largest palm oil producer in the world with around 41% of the total world supply in the year 2009 to 2010. Most of the POFA produced is typically disposed of in landfills. A few researchers have studied the use of POFA in concrete [7 – 10]. Namini [11] stated that POFA can act as a supplementary cementitious material in concrete. POFA is greyish and almost dark in colour. According to Ekiti et al. [12], POFA can be used as a replacement of cement because it contains a high pozzolanic material, which will help to increase the durability as well as compressive strength of concrete.

Eggshell is a waste produced from the food industry such as restaurants, poultry farms and bakery shops. Re-using eggshells promotes recycling of farm waste and prevent its diversion into landfills. The majority of eggs are utilized in egg breaking plants for mass production of liquid eggs for use in food and non-food related products [13]. Hincke et al. [14] stated that the outer eggshell is made up of calcium carbonate CaCO_3 . According to Pliya and Cree [13], 1 billion eggs would produce 6600 tonnes of limestone powder and the amounts would not be enough for concrete industry but in total it could be used as partial cement replacement. A limited number of studies have been conducted on the utilization of eggshell waste as an alternative material. Amaral et al. [15] investigated soil bricks containing 0% to 30% of eggshell powder (ESP) as partial replacement of cement. The compressive strength increased by 7% and 12% when cement in bricks was replaced from 10% to 12% compared to bricks without ESP, respectively. However, when 30% ESP was added, the compressive strength decreased by only 2%.

This paper focuses mainly on the effect of different mix proportions of POFA and ESP as partial cement replacement concrete.

2 Experimental Program

2.1 Material and Mix Proportion

Raw POFA was obtained from the Unique Palm Oil Mill, Mukah, Sarawak, Malaysia and oven dried for 24 hours. The ash used in this research was produced by burning the husk fibre and shell of the palm oil fruit. The POFA was then sieved at passing through size of 300 μm sieve. ESP used in this research was blended using a blender and sieved in a 75 μm sieve. The POFA and ESP were varied as 10% cement replacement by weight. Figures 1(a) and 1(b) show ESP and POFA specimens used in this study. The cement used in this study was Ordinary Portland (OPC) Type 1. 10 mm well graded crushed granite and locally available river sand were used as coarse and fine aggregates, respectively. The concrete mixing procedure consisted of various ratios of ESP and POFA at 10% cement replacement, OPC, fine and coarse aggregates. Concrete strength was designed to achieve a compressive strength of 30 N/mm^2 at 28 days. Water to cement ratio was fixed at 0.54. The mix proportions of POFA:ESP at 10% cement replacement were as follows: (i) 0% (control), (ii) 10% POFA:0% ESP, (iii) 8% POFA:2% ESP, (iv) 6% POFA:4% ESP, (v) 4% POFA:6% ESP, (vi) 2% POFA:8% ESP and (vii) 0% POFA:10% ESP. Table 1 shows these mix proportions. Three specimens were casted for each mixture of concrete giving a total of twenty-one (21) specimens. The concrete specimens were cured in a water tank for 28 days before carrying out the compressive strength testing.



Fig. 1. Materials: a) Eggshell Powder (ESP) and b) Palm Oil Fuel Ash (POFA).

Table 1. Mix Proportions of specimens.

Mix Proportion	Coarse Aggregate (kg)	Fine Aggregate (kg)	Cement (kg)	Eggshell Powder (kg)	POFA (kg)	Water (kg)
Normal mix	3.659	1.885	1.541	-	-	0.769
E10%	3.659	1.885	1.387	0.154	-	0.769
E8%,P2%	3.659	1.885	1.387	0.124	0.031	0.769
E6%,P4%	3.659	1.885	1.387	0.093	0.062	0.769
E4%,P6%	3.659	1.885	1.387	0.062	0.093	0.769
E2%,P8%	3.659	1.885	1.387	0.031	0.124	0.769
P10%	3.659	1.885	1.387	-	0.154	0.769

E – ESP, P – POFA

2.2 Slump Test

The concrete specimens were tested for workability using the slump cone test. The main purpose of the test is to determine the effect of adding ESP and POFA on concrete workability. The testing procedure followed the method given in BS EN 12390-2 [16].

2.3 Density

Density of concrete is the mass to volume ratio. Concrete density depends on the density of the fine and coarse aggregates, the amount of entrapped air, water and cement contents. Normal concrete density is about 2400 kg/m³. Before conducting the compressive test, the mass of concrete needs to be measured. The mass of the concrete cube can be obtained using a weighing scale. The density can be calculated using Equation 1:

$$\rho = \frac{\text{Mass of Concrete(kg)}}{\text{Volume of cured concrete (m}^3\text{)}} \quad (1)$$

2.4 Compressive Strength Test

Twenty one cubes of (100 × 100 × 100) mm were used to determine the compressive strength. The compressive strength mix was designed for 30 N/mm² for each mixture after

28 days of curing. The compression test was carried out using ADR Auto V2 3000 kN compression machine as shown in Fig. 2. The pace rate for the compression test applied was 7.0 kN/s. The loading pace was constantly applied until the specimens visibly failed. The compressive strength for each specimen was determined after 28 days of curing in water. The procedures used in carrying out each test were in accordance with BS EN 12390-3 [17].

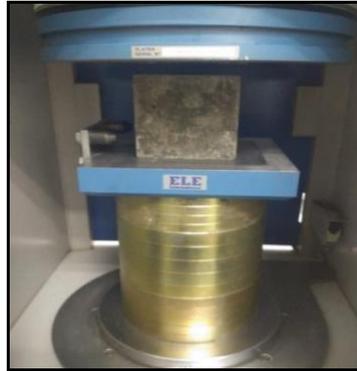


Fig. 2. The compression test machine.

3 Results and Discussion

3.1 Workability

Fig. 3 shows the workability of normal mix concrete and POFA-ESP concrete. It is observed that concrete with 10% of ESP increases the workability as the slump height achieved was 98 mm while the normal mix slump was 91.5 mm. When POFA was added to concrete, workability started to decrease. With the gradual addition of more POFA, a corresponding decrease in slump height ensued. At 10% POFA the slump height was 22 mm.

According to Awal [18], the influence of POFA fineness affects both fresh and hardened state properties of concrete. Due to this, a higher water demand was seen in low fineness POFA in concrete compared to high fineness POFA. Hussin et al. [19] showed that unground POFA with low fineness ash particles had larger and higher porosity particles compared to ground POFA with tinier, irregular, and crushed formed particles.

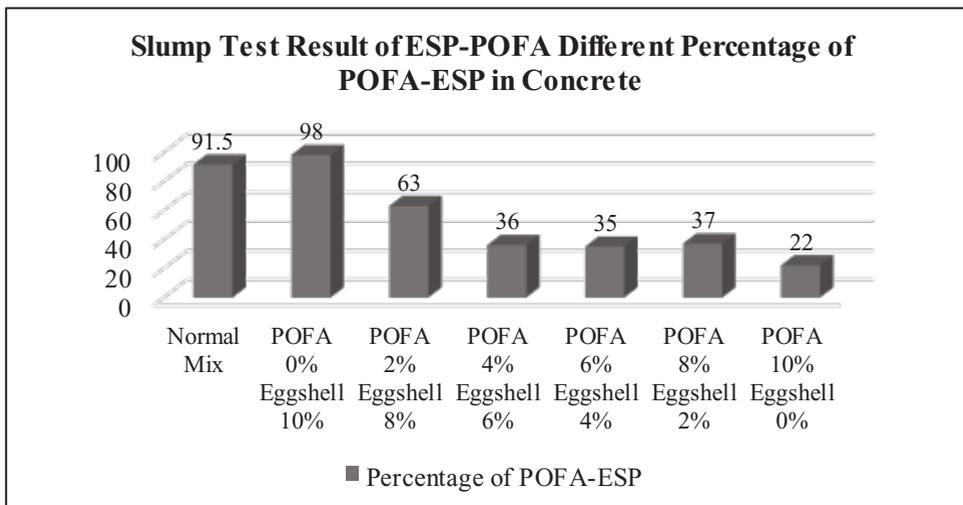


Fig. 3. Density versus percentages of POFA-ESP in concrete.

3.2 Density of Concrete

It is shown in Fig. 4 that the density of normal mix concrete using Ordinary Portland cement is 2415 kg/m³. The density of concrete was reduced when the eggshell powder and palm oil fuel ash were incorporated in the mix. The highest reduction in density was 2.36% due to the inclusion of 10% ESP in the concrete. The density of the concrete mixtures incorporating 6% POFA:4% ESP and 10% POFA were both reduced by 2.28%. The density of concrete containing 8% POFA:2% ESP was reduced by 1.6% compared to the normal mix concrete. Concrete with 4% POFA:6% ESP had the least significant decrease in density at 0.9% reduction compared to normal mix concrete. The only mixture with an increase in density was the 2% POFA:8% ESP.

The decrease of concrete density when incorporating POFA and ESP might be caused by the low specific gravity of the waste material compared to cement. According to Hussin, et al. [19], cement particles are generally heavier than POFA as the specific gravity of OPC is 3.15 compared to the specific gravity of POFA, which is 2.18. Another study by Yerramala [20] showed that the specific gravity of ESP is 2.37, which is appreciably lower than that of OPC. However, the 2% POFA:8% ESP mixture showed that the density of the POFA-ESP concrete increased by 0.74% compared to OPC concrete. This might be due to weight increase from the aggregates in the POFA-ESP concrete that contributed to this increase in density, in comparison to the OPC concrete density.

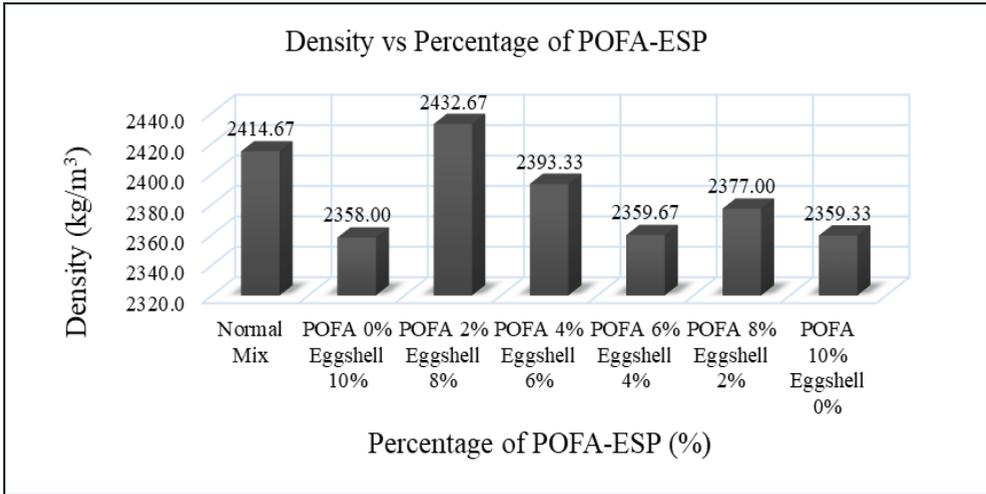


Fig. 4. Density versus percentages of POFA-ESP in concrete.

3.3 Compressive Strength

Fig. 5 shows the relationship between the various mixtures of POFA-ESP and compressive strength. The targets mean strength design for concrete was 30 N/mm² at 28 days. The normal mix design of OPC concrete had the highest compressive strength of 42.37 N/mm² in comparison to the concrete incorporating POFA and ESP. It is shown in Figure 5 that the optimum strength of ESP-POFA concrete achieved was 38.6 N/mm² at 28 days. This was for the concrete mixture with 6% POFA:4% ESP cement. On the other hand, concrete incorporating 4% POFA: 6% ESP had the lowest compressive strength of 34.63 N/mm².

A study by Jaturapitakkul et al. [21] found by increasing the ratio of ground POFA fineness increased significantly the rate of pozzolanic activity and compressive strength. Hussin et al. [19] prepared POFA by sieving through a 300 μm sieve and then was ground to obtain its final fineness passing the 45 μm sieve. As a result, partial cement replacement with 45 μm POFA incorporated in aerated concrete had higher compressive strength in comparison to normal aerated concrete [19]. It was shown that the finer particles of POFA contributed to a better pozzalanic material, which can be used as an alternative cement replacement [21].

Moreover, Elaty [22] who did an extensive research study to predict the strength of concrete mixtures, reported values for concrete strength after 28 days of curing from Lea's Chemistry of Cement and Concrete and other references [23]. The values range from 36.1-56.5 N/mm². Most of the values found in this research and shown in Figure 5 fall within this range, indicating that using POFA and ESP as partial replacements for cement concrete is viable and strength-wise feasible.

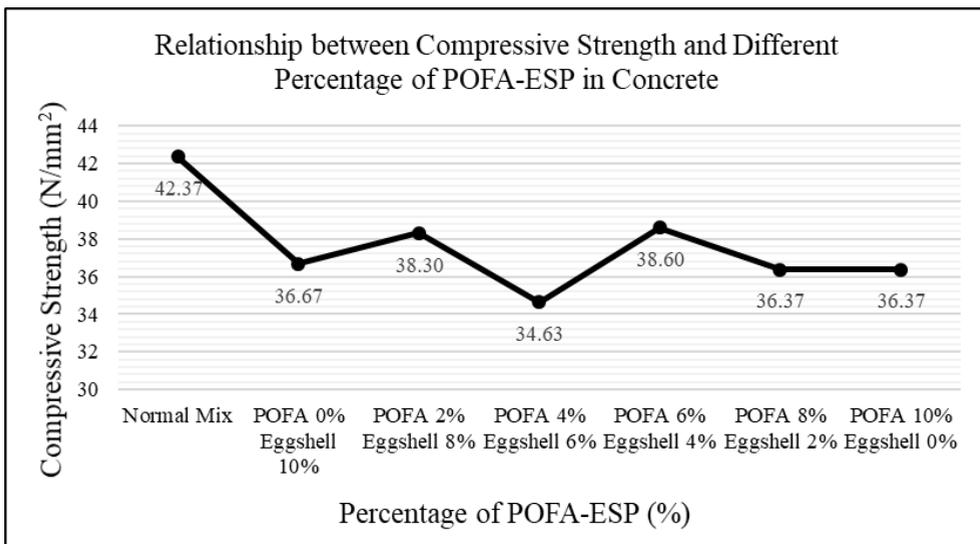


Fig. 5. Relationship between percentages of POFA-ESP and compressive strength.

4 Conclusions

Density, workability and compressive strength testing have been carried out on several POFA-ESP concrete mix proportions. The aim was to replace 10% of cement by weight and investigate experimentally the newly-formed mixtures. Based on the results obtained and above discussion, the following conclusion can be drawn:

POFA-ESP concrete exhibits lower strength development compared to OPC concrete. The results showed that 6% POFA: 4% ESP had the highest strength out of all POFA-ESP concrete mixtures tested. POFA fineness should be increased by grinding and sieving through a 45 µm sieve in order to get higher compressive strength of concrete. The density and workability of POFA-ESP concrete is generally lower compared to normal mix concrete. However, POFA-ESP concrete is viable and strength-wise feasible and can be utilized as partial cement replacement in concrete and used for structural and non-structural purposes. Furthermore, the usage of POFA and ESP will help in reducing environmental problems and landfill disposal problem.

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